VOLUME 65 [W. B. No. 1224] NUMBER 12

MONTHLY WEATHER REVIEW

DECEMBER 1937

CONTENTS

UNITED STATES DEPARTMENT OF AGRICULTURE

WEATHER BUREAU

WASHINGTON, D. C.

1938

CORRECTION

Volume 65, August 1937, page 313, 19th line down, for "30th, to the northeast", read "24th, to the northeast".

Volume 65, November 1937, page 408: *Charles City, Iowa*, the mean sea-level pressure "30.00" should be "30.10"; pressure departure "−0.08" should be "+0.02."

MONTHLY WEATHER REVIEW

Editor, EDGAR W. WOOLARD

VOL. 65, No. 12
W. B. No. 1224

DECEMBER 1937

CLOSED FEBRUARY 3, 1938
ISSUED MARCH 15, 1938

INTERNATIONAL STANDARD PROJECTIONS FOR METEOROLOGICAL CHARTS

By W. R. GREGG and I. R. TANNEHILL

[Weather Bureau, Washington, D. C., December 1937]

At Salzburg, Austria, on September 16, 1937, the Commission on Projections for Meteorological Charts, as it is now officially designated, adopted nine resolutions, eight of which contain recommendations regarding meteorological charts. The other resolution was a decision to change the name of the Commission; it had previously been known as the "Commission on Map Projections." Later, the eight resolutions dealing with meteorological charts, after slight modifications, were adopted by the International Meteorological Committee. It is the purpose of this article to give briefly the history of action in the International Meteorological Organization on projections and scales of charts, to state the objectives of the eight resolutions of Salzburg, and to discuss briefly the projections selected.

HISTORICAL

Organized efforts to secure uniformity in the projections and scales of meteorological charts are of comparatively recent origin. Although the synoptic chart was made practical by the invention of the electric telegraph, it was not until the development of radio communication that international exchanges of weather information made it possible to extend the charts over the oceans and to other continents. As one result of the extension, map projections that had been used for charting small areas proved in some cases to be unsuitable for large areas, hence additional projections were employed. Thus it came about that different meteorological services that began to draw weather maps extending over the same region used different map projections for that region. One example, which is by no means the outstanding one, is the daily chart of the Northern Hemisphere; both the stereographic and the equidistant azimuthal projections came into use for this purpose.

One of the first meteorologists to recognize the growing need for uniformity was V. Bjerknes. Nearly 20 years ago he declared that numerous and important problems might be solved with the aid of observations already assembled in the archives of different bureaus, but that the difficulties in making these observations serve a special purpose were unsurmountable for the individual scholar. He added that, in particular, the synoptic charts representing the momentary states of the atmosphere over large areas of the earth, in all the necessary details and exactitude, were excessively difficult to assemble. His proposal was that there be entered at the central bureau of each country, on the appropriate maps, all the available observations taken in that country and that there be employed, by the different bureaus, maps that may be simply superimposed or juxtaposed.

Bjerknes' proposal was made at the International Conference in Paris in 1919 and was published as an appendix to the report of the meeting.[1] His views were more fully expressed in 1920 in connection with geophysical charts in general.[2] His proposals were adopted in Resolution 34 of the Eleventh Ordinary Meeting in London in 1921.[3] This resolution specified three conformal projections, one for the polar regions on a plane cutting at 75°, another for middle latitudes on a cone intersecting at 30° and 60°, and a third for the equatorial regions on a cylinder cutting at 15°; the scales were 1:2,500,000; 1:5,000,000; 1:10,000,000; and 1:20,000,000, with recommendation that the scale 1:10,000,000 be used whenever possible.

At a meeting of the Commission on Maritime Meteorology at Copenhagen in 1929, special maps for the Atlantic Ocean and the Northern Hemisphere were discussed and the following were recommended: For the Atlantic, a monoconic projection with intersections at 30° and 60° latitude and, for the Northern Hemisphere, a circumpolar map on an orthogonal projection with the plane through 60° latitude. This proposal was adopted as Resolution 22.[4] As the result of this resolution there came into use a North Atlantic map on a conic projection with standard parallels at 30° and 60° and scale 1:20,000,000, also a Northern Hemisphere map on an equidistant azimuthal projection with standard parallel at 60° and scale 1:30,000,000. These two scales were recommended at that time by the Maritime Commission as the ones best suited for these purposes.[5]

At the same meeting (1929), Resolution 97 was adopted as follows:

1. The subcommission recognizes the great importance to all branches of meteorological work of finding the best system of maps on the principles laid down in Resolution 34, paragraph 1, of the London Meeting 1921. It recommends for this purpose the appointment of a joint subcommission composed of members from all the commissions interested.
2. Until the joint subcommission has completed its work it is recommended that services should adhere as far as possible to the whole Resolution 34 of the London Meeting, 1921.

The joint subcommission authorized by this resolution was nominated in May 1935, with 6 members, one from each of the following Commissions: Maritime Meteorology, Synoptic Weather Information, Investigation of the Upper Air, Terrestrial Magnetism and Electricity, Reseau Mondial and Polar Meteorology, Climatology.

At Warsaw in 1935 this joint subcommission recommended that Resolution 34 of London be altered so that

[1] Great Britain Meteorological Office. Report of the Proceedings of the Fourth International Conference of Directors of Meteorological Institutes and Observatories and of the International Meteorological Committee, Paris, 1919. M. O. 239, appendix 1, pp. 32, 33. London, 1921.

[2] Bjerknes, V. Sur les projections et les échelles à choisir pour les cartes géophysiques. *Geografiska Annaler*, Vol. I, pp. 1-12, 1920.

[3] Great Britain Meteorological Office. Report of the Eleventh Ordinary Meeting, London, 1921. M. O. 248, pp. 29, 30. London, 1922.

[4] International Meteorological Organization. Procès-verbaux des séances de la conférence internationale des directeurs du comité météorologique internationale et de diverses commissions à Copenhague, septembre 1929. pp. 31, 32. Utrecht, 1929.

[5] *Ibid.*, p. 220.

the plane of the polar charts cut at 50° instead of 75°, and the cylinder for equatorial charts cut at 25° instead of 15°.[6] Hope was expressed that a continued study of the problem would lead to the adoption of 2 or 3 types of world maps suitable for general use.

In Resolution 114 at Warsaw the joint subcommission was changed to an independent commission. The President of the International Meteorological Organization then appointed W. R. Gregg president of the new commission.

In reviewing the work of the organization on map projections up to that time (1935), it will be noted that the provisions of the original London resolution had been changed with regard to the standard parallels of polar and equatorial projections, and also by the addition of a scale of 1:30,000,000. Furthermore, an equidistant azimuthal projection had come into use for the Northern Hemisphere, although this projection is not strictly conformal but is a sort of compromise between conformality and equivalence.

THE SALZBURG RESOLUTIONS

At the meeting of the Commission in Salzburg on September 16, 1937, the following resolutions were drawn up and were later adopted by the International Meteorological Committee:

RESOLUTION I: The Commission decides that its name be changed to "Commission on Projections for Meteorological Charts."

RESOLUTION II: The Commission recommends that three conformal (orthomorphic) projections be used for synoptic meteorology, as follows:

(a) The stereographic projection for the polar regions on a plane cutting the sphere at 60°.

(b) The Lambert conformal conic projection for middle latitudes, the cone cutting the sphere at 30° and 60°.

(c) Mercator's projection for the equatorial regions, with true scale at 22½°.

RESOLUTION III: The Commission decides that the stereographic polar projection may be extended to cover a hemisphere; that Lambert's conformal conic projection may be extended poleward from 60° or equatorward from 30° as may be necessary to produce a continuous chart, and that Mercator's projection may be extended to make a chart of the world or of any large part of the world when the region of primary interest is in the equatorial zone.

RESOLUTION IV: The Commission reports that it has been unable to find any conformal projection that will provide a wholly satisfactory chart of the world in one section for synoptic meteorology; that Mercator's projection is the nearest approach, but its distortions in high latitudes are serious; that two stereographic charts of the hemisphere placed side by side may be used as a meteorological chart of the world in two sections.

RESOLUTION V: The Commission recommends that the following scales be used for manuscript (working) charts:

(a) For large-area charts of the world, a hemisphere, or a large part of a hemisphere, the scales along the standard parallels should be:

1 : 20,000,000 (large area),
1 : 30,000,000 (a hemisphere),
1 : 40,000,000 (world).

(b) For charts of a continent or an ocean or considerable parts of either or both on a single chart, the scales along the standard parallels should be:

1 : 7,500,000,
1 : 10,000,000,
1 : 15,000,000.

(c) For detailed charts the scales should be:

1 : 1,000,000,
1 : 2,500,000,
1 : 5,000,000.

(d) That preference be given whenever possible to the following scales:

For the hemisphere, 1 : 30,000,000.
For a large area, 1 : 20,000,000.
For a large continent or ocean, 1: 10,000,000.
For detailed charts, 1 : 5,000,000.

[6] International Meteorological Organization. Conférence des directeurs à Varsovie, 6-13 septembre, 1935. Tome I, p. 104. Leyde, 1936.

RESOLUTION VI: The Commission recommends that the directors of meteorological services adopt one of the projections and scales mentioned in Resolution No. V for each chart used for synoptic meteorology, whether the charts are prepared in single copies by hand (manuscript) or in quantities for distribution and exchange (printed or duplicated). If this is not possible owing to costs and other factors, that whenever a change becomes necessary, effort will be made to utilize projections and scales from the international standards adopted by this Commission.

RESOLUTION VII: The Commission recommends that every chart for meteorological purposes have printed on its face the name of the projection and the scale at the standard parallel, 22½°, 30° or 60° (both 30° and 60° in the case of the conic projection); and that the scales be also printed on the chart at different latitudes.

RESOLUTION VIII: The Commission suggests that, in principle, the standard projections for climatological uses should be equal-area; and that when special charts for climatology are required, the following are suggested:

(a) An equal-area azimuthal projection of the polar regions, on a plane cutting the sphere at 60°.

(b) An equal-area conic projection of middle latitudes with intersections at 30° and 60°.

(c) An equal-area cylindrical projection of the equatorial regions, the cylinder cutting the sphere at 22½°.

Any of these three projections may be extended as required to produce a continuous map of the region to be charted.

RESOLUTION IX: The Commission recommends that, whenever a meteorological service changes the projection or scale of any of its existing charts or adopts an additional chart, the director of the Service shall send to the president of the Commission on Projections for Meteorological Charts 30 copies of the chart in order that the members of the Commission may be informed regarding all charts in regular use.

The Commission for Synoptic Weather Information adopted a resolution formulated in the Symbols Subcommission, from which the following is quoted:

> The Commission emphasizes the importance of making universal use of the Warsaw station model and symbols and the advantages of the use of synoptic charts on the scale 1 : 10^7. The Commission also recommends that services which find difficulty in plotting should communicate with the Chairman of the Symbols Subcommission with regard to the technical methods of giving effect to this recommendation.

COMMENTS ON THE SALZBURG RESOLUTIONS

A stereographic map is obtained by a perspective projection of a sphere onto a plane, from a point on the surface of the sphere diametrically opposite the point at the center of the map; e. g., in a projection of the Northern Hemisphere with the North Pole at the center, the point of projection is at the South Pole. When the ellipticity of the earth is taken into account, the ellipsoid is first mapped conformally upon a sphere, and the sphere then projected stereographically onto a plane. The parallels of latitude are concentric circles, and the meridians are radii of these circles. It is the only azimuthal projection in which there is no angular distortion and in which every circle is projected as a circle (fig. 1). It is conformal, that is, at each point the scale is the same in all directions—in particular along both the meridians and the parallels—so that length and breadth are increased in the same ratio; and hence angles, and the true shapes of *small* areas, are preserved.[7] The scale varies with latitude, but is constant along parallels.

The method of projecting the sphere is shown in figure 2 (the position of the plane upon which the projection is made is immaterial, merely changing the scales at all latitudes in a common ratio). In the preliminary conformal projection of the ellipsoid onto a sphere, the parallel of latitude ϕ on the ellipsoidal earth projects into a parallel on the sphere at a different latitude ϕ' which is called the isometric or conformal latitude; to an accuracy sufficient for the present purpose $\phi-\phi'=[2.8421554]$

[7] The stereographic polar projection is used by the U. S. Weather Bureau for its Northern Hemisphere chart.

sin $2\phi-[9.98969-10]$ sin 4ϕ seconds, on the International Ellipsoid. The stereographic polar projection is easily constructed either graphically as shown in figure 2 or by computing the radii $Np, Nq,$ . . . of the parallels of latitude on the map. When the earth is considered as a sphere, the

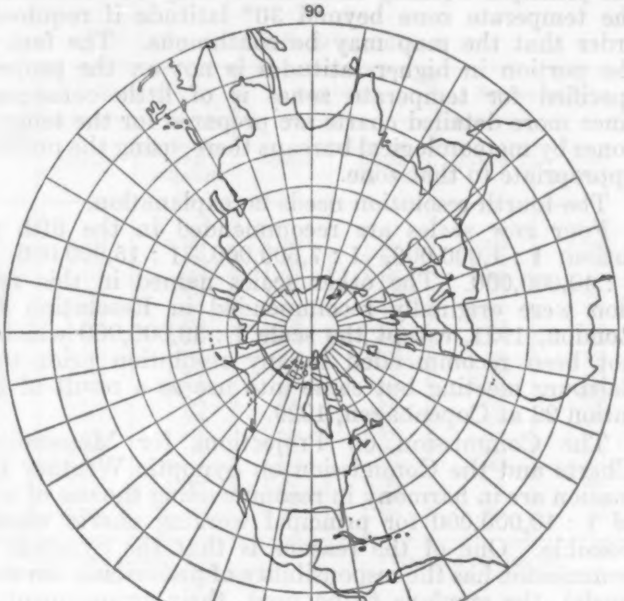


FIGURE 1.—Stereographic polar projection of the Northern Hemisphere.

arcs $NP, NQ,$ . . . are taken equal to the polar distances p of the parallels that are being mapped, and the radii are obviously $r=c \tan \frac{p}{2}$ where c is the constant determined by the standard scale; when the ellipticity of the earth is taken

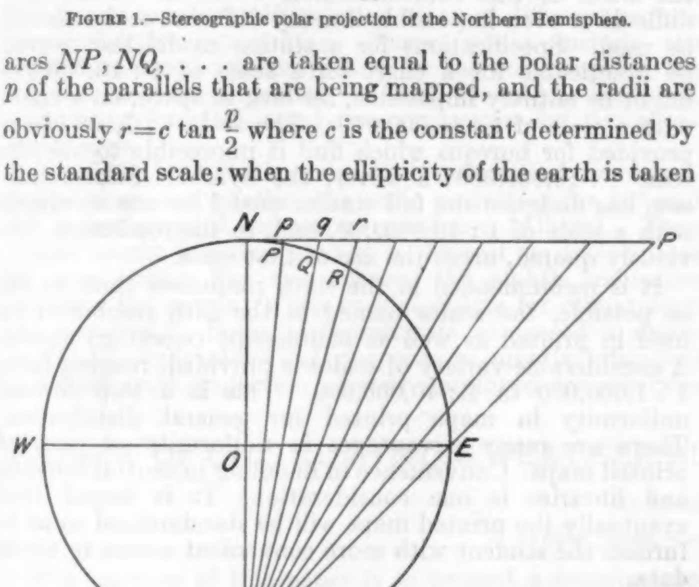


FIGURE 2.—Construction of the stereographic polar projection with the point of projection at the south pole. *NESW*, plane of meridian; *Npqr*, intersection of plane *NESW* with mapping plane tangent at north pole *N*.

into account, the arcs $NP, NQ,$ . . . are taken equal to the isometric colatitudes z obtained from ϕ, and the radius of the parallel of ϕ on the map is $r=k \tan \frac{z}{2}$. The meridian of longitude λ intersects the prime meridian on the map at the true angle λ.

The stereographic projection with one of the poles in the center has increasing exaggeration of areas toward the equator. When Northern Hemisphere charts were first coming into use, there were relatively few reports from the tropics, hence the exaggeration of area of the stereographic projection in that region was objectionable. Relatively, much more charting space was needed at that time for the numerous reports in middle latitudes. For this reason, the equidistant azimuthal projection of the hemisphere was preferred. In recent years there has been an increase in the number of reports from land stations and ships in the tropics, hence the stereographic projection is now considered preferable to the equidistant projection for synoptic

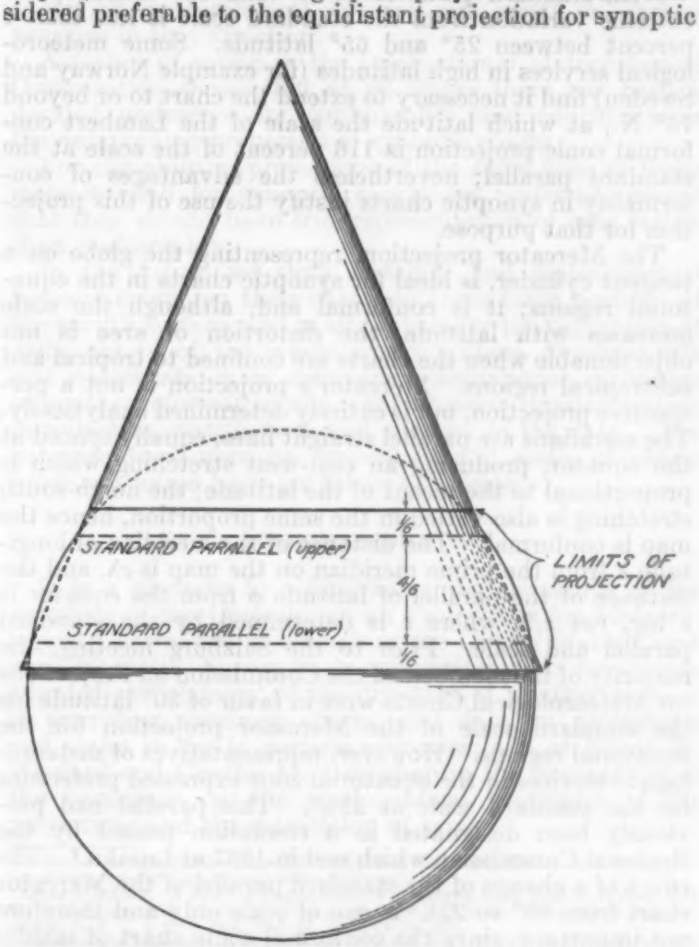


FIGURE 3.—Diagram showing the intersections of a cone and a sphere along two parallels of latitude. This diagram illustrates the principle of the Lambert conformal conic projection, but the projection cannot be constructed graphically by perspective projection; the standard parallels, furthermore, are not quite at the intersections.

charts, because the angular distortion in the latter is objectionable in plotting wind directions.

Lambert's conformal conic projection with two standard parallels is ideal for synoptic charts in middle latitudes.[8] The essential principle of the projection is illustrated in figure 3, which shows the intersections of a cone and a sphere along two parallels, although this projection (unlike the stereographic) is determined only analytically and not projectively, and hence is not completely represented by this figure: The earth is projected on the intersecting cone, but not perspectively; the parallels of latitude are concentric circles, and the meridians are radii of these circles. The scale varies with latitude, but is constant along parallels. The two selected parallels along which the scale is held at the standard value are practically, though not exactly, those at which the cone intersects. The

[8] This projection is used by the U. S. Weather Bureau for its Chart AB for airway service.

radius of the parallel of latitude ϕ on the map is $r = K \tan^l \frac{z}{2}$, where z is the isometric colatitude and K, l, are constants determined by the standard parallels and scale; the meridian of longitude λ intersects the prime meridian at the angle $l\lambda$. On the International Ellipsoid, with the meter as unit of length, and standard parallels at 30° and 60°, l=0.71569, log K=7.05758; neglecting the ellipticity of the earth, l=0.71557, log K=7.058297.

With standard parallels at 30° and 60° latitude, the extreme variation from the standard scale is less than 4 percent between 25° and 65° latitude. Some meteorological services in high latitudes (for example Norway and Sweden) find it necessary to extend the chart to or beyond 75° N., at which latitude the scale of the Lambert conformal conic projection is 116 percent of the scale at the standard parallel; nevertheless the advantages of conformality in synoptic charts justify the use of this projection for that purpose.

The Mercator projection, representing the globe on a tangent cylinder, is ideal for synoptic charts in the equatorial regions; it is conformal and, although the scale increases with latitude, the distortion of area is not objectionable when the charts are confined to tropical and subtropical regions. Mercator's projection is not a perspective projection, but is entirely determined analytically. The meridians are parallel straight lines, equally spaced at the equator, producing an east-west stretching which is proportional to the secant of the latitude; the north-south stretching is also varied in the same proportion, hence the map is conformal. The distance of the meridian of longitude λ from the prime meridian on the map is $c\lambda$, and the distance of the parallel of latitude ϕ from the equator is $c \log_e \cot z/2$, where c is determined by the standard parallel and scale. Prior to the Salzburg meeting, the majority of the members of the Commission on Projections for Meteorological Charts were in favor of 30° latitude for the standard scale of the Mercator projection for the equatorial regions. However, representatives of meteorological services in the equatorial zone expressed preference for the standard scale at 22½°. This parallel had previously been designated in a resolution passed by the Regional Commission which met in 1937 at Lusaka.[9] The effect of a change of the standard parallel of the Mercator chart from 30° to 22½° is one of scale only and therefore not important, since the conformal conic chart of middle latitudes and the Mercator chart of the equatorial zone cannot be made to coincide along the thirtieth parallel, even with the same scale there, except by rolling contact.

All of these projections (polar stereographic, Lambert conformal conic, and Mercator) have only rectilinear meridians and concentric circular parallels with their common center at the common intersection of the meridians (at infinity in the Mercator), and may therefore be extended indefinitely in longitude, reaching around the world and repeating any region if necessary; and, furthermore, it makes no difference what meridian is placed in the middle of the map—all geographical features remain unchanged. These are essential properties of projections for international use, because European countries, for example, may wish to have the central meridian of their synoptic charts at 15° E., while on North American charts the central meridian may be at 90° W. Thus the maps of different countries, when on the same projection and scale, may be simply superimposed or juxtaposed, and will fit together.

[9] International Meteorological Organization. Regional Commission No. 1 (Africa). Minutes of the first meeting held at Lusaka, the capital of northern Rhodesia, August 17 to 26, 1936, pp. 25, 26. Utrecht, 1937.

In the third resolution there is provision for the extension of charts on any of the three projections into regions beyond those specified in the second resolution. For example, if the region of chief interest lies in the equatorial zone, the Mercator projection should be used for the principal working chart but it may be extended into the temperate zone beyond 30° latitude if required, in order that the map may be continuous. The fact that the portion in higher latitudes is not on the projection specified for temperate zones is of little consequence, since more detailed charts are prepared for the temperate zones by meteorological bureaus there, using the projection appropriate to that zone.

The fourth resolution needs no explanation.

Four new scales are recommended in the fifth resolution: 1 : 1,000,000, 1 : 7,500,000, 1 : 15,000,000, and 1 : 40,000,000. The other scales named in this resolution were originally recommended in Resolution 34 at London, 1921, except the scale 1 : 30,000,000 which had not been recommended in any resolution prior to the Salzburg meeting but came into use as a result of Resolution 22 at Copenhagen, 1929.

The Commission on Projections for Meteorological Charts and the Commission on Synoptic Weather Information are in harmony in recommending the use of a scale of 1 : 10,000,000 for principal working charts whenever possible. One of the reasons is that the Symbols Subcommission has the responsibility of prescribing the station model, the symbols to be used, their arrangement, and the number of items for each station. It is evident that the work of this subcommission would be exceedingly difficult or even impossible if many different scales should be used. Specifications for a station model that would be practicable for a chart on a scale of 1 : 10,000,000 might be entirely impossible, for lack of space, on a chart with a scale of 1 : 15,000,000. The scale 1 : 7,500,000 is provided for bureaus which find it impossible to use the scale 1 : 10,000,000; however, the Symbols Subcommission has designed the full station model for use on charts with a scale of 1 : 10,000,000, and, in the resolution previously quoted, urges the use of that scale.

It is recommended in the sixth resolution that, as far as possible, the scales named in the fifth resolution be used in printed as well as manuscript (working) charts. A considerable variety of scales is provided, ranging from 1 : 1,000,000 to 1 : 40,000,000. This is a step toward uniformity in maps printed for general distribution. There are many advantages in uniformity of sizes of printed maps: Convenience in handling in central bureaus and libraries is one consideration. It is hoped that eventually the printed maps will be standardized so as to furnish the student with more convenient access to world data.

In the seventh resolution it is recommended that the name of the projection, and the scale at the standard parallel(s), be printed on the map. An indication of scales at different latitudes is also included, which can be accomplished by placing at the end of each parallel of latitude at 5° intervals the ratio of the scale at that parallel to the scale at the standard parallel. Table 1 gives these ratios for the three standard projections at 5° intervals of latitude on both a sphere and an ellipsoid. The resolutions do not explicitly specify the figure and size of the earth that are to be used in computing the projections, although a "sphere" is referred to in Resolutions II and VIII. Tables computed by Sverdrup for the Lambert projection are given in Bjerknes' paper [2] and have already been used by several countries; the figure of the earth on

which they are based is not stated. For the purpose of meteorological charts, the inaccuracy of considering the earth as a sphere is unimportant, and the differences between different ellipsoids are negligible; but if an ellipsoid be used, presumably it should be the International Ellipsoid, on which table 1 has been computed.

TABLE 1.—*Scale variations*

Latitude	Mercator [1]		Lambert [2]		Stereographic [3]	
	Sphere	International ellipsoid	Sphere	International ellipsoid	Sphere	International ellipsoid
°						
0	0.924	0.924	1.283	1.281	1.932	1.860
5	.927	.928	1.210	1.208	1.777	1.712
10	.938	.938	1.149	1.148	1.590	1.586
15	.956	.957	1.099	1.098	1.482	1.480
20	.983	.983	1.058	1.058	1.390	1.388
25	1.019	1.019	1.025	1.025	1.312	1.310
30	1.067	1.066	1.000	1.000	1.244	1.243
35	1.128	1.127	.982	.982	1.186	1.185
40	1.206	1.205	.970	.970	1.136	1.136
45	1.307	1.305	.966	.966	1.093	1.093
50	1.437	1.435	.968	.969	1.057	1.057
55	1.611	1.608	.979	.979	1.026	1.026
60	1.848	1.844	1.000	1.000	1.000	1.000
65	2.186	2.181	1.033	1.033	.979	.979
70	2.701	2.694	1.084	1.083	.962	.962
75	3.570	3.560	1.162	1.162	.949	.949
80	5.320	5.306	1.293	1.292	.940	.940
85	10.600	10.570	1.566	1.564	.934	.936

[1] Standard parallel, 22½°.
[2] Standard parallels, 30° and 60°.
[3] Standard parallel, 60°.

The Commission suggested in the eighth resolution that equal-area charts be used for climatological purposes, i. e. maps in which the relative areas of different regions are correctly represented. These would include the azimuthal equal-area projection for the polar regions, the equal-area conic projection (Albers') for middle latitudes, and the cylindrical equal-area projection for the equatorial zone.

In middle latitudes it makes little difference for meteorological purposes whether the conic projection for 30° and 60° is conformal (Lambert) or equal-area (Albers). They are so nearly identical that it is difficult to differentiate by inspection. For this reason, the eighth resolution contains the words "when special charts for climatology are required." Some meteorologists expressed a desire to use (for climatological purposes in middle latitudes) the conformal projection already employed for synoptic purposes, rather than prepare a special map on an equal-area projection that differs so little. Scales were not specified.

The ninth resolution requires no explanation.

CONCLUSION

While much remains to be done before complete uniformity is attained in manuscript and printed charts for meteorological work, the Salzburg resolutions, if adhered to by all meteorological services, will result in marked progress in that direction.

A review of action in the International Meteorological Organization shows that at all stages there has been a decided preference for conformality and continuity as the outstanding properties of synoptic charts.

For climatology, projections of the same type as those recommended for synoptic charts are preferred, except that they should have true representation of area rather than conformality.

In the future we shall certainly find meteorological bureaus extending their charts to cover large portions of the earth's surface, and in all probability the beginnings of daily charts of the whole world. These developments will necessitate more extensive international exchanges of weather information and more intensive standardization in collection, distribution, and charting of the data. The Salzburg resolutions on projections and scales of charts provide a sound basis for future expansion.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the assistance of the members of the Commission on Projections for Meteorological Charts, and of officials of the United States Coast and Geodetic Survey,[10] in preparing the resolutions adopted at Salzburg; of the directors of weather services in providing specimen charts, and data on projections and scales in use in various countries; and of Edgar W. Woolard and Charles M. Lennahan in the preparation of the comments on the mathematical properties of the projections and the calculation of table 1.

[10] Readers desiring further information regarding the theory, construction, and properties of the projections are referred to the following:
Oscar S. Adams. A study of map projections in general, *U. S. C. & G. S. Spec. Pub. 60*, Washington, 1919. Charles H. Deetz and Oscar S. Adams. Elements of map projection, *U. S. C. & G. S. Spec. Pub. 68*, Washington, 1934.
Tables of the International Ellipsoid are contained in *U. S. C. & G. S. Spec. Pub. 200*.

REVIEW OF UNITED STATES WEATHER BUREAU SOLAR RADIATION INVESTIGATIONS

By IRVING F. HAND

[Weather Bureau, Washington, D. C., June 1937]

The purpose of this paper is to present a summary to date of the methods employed and the results obtained in the solar radiation investigations conducted by the Weather Bureau. Many data are here published for the first time, while several tables and charts that have previously appeared in the MONTHLY WEATHER REVIEW are revised and brought up to date. Numerous references to the literature are included, to enable readers who so desire to readily locate further details (a useful general bibliography of some of the earlier literature is given by Kimball, *Bull. Mt. Weath. Obs.*, 3: 118–126, 1910).

INTRODUCTION

Radiation from the sun is the ultimate source of all except a practically negligible portion of the continual supply of energy that is essential for the maintenance of plant and animal life on the earth and for the operation of nearly all natural phenomena on the surface of the earth; in particular, the amount and the distribution in time and space of the solar radiation which is intercepted by the earth is the primary generating cause of the physical activities in the atmosphere that determine weather and climate. The study of the radiation from the sun is therefore of direct and fundamental importance to numerous different fields of both pure and applied science, including meteorology.

The Weather Bureau first began to devote attention to solar radiation measurements in 1901. (See *Rept. of the Chief of the Weather Bureau*, 1901–1902, p. xvii; and C. F. Marvin, MO. WEA. REV., 29: 454–458, 1901.) In July of

that year, three copies of Angström's electric compensation pyrheliometer were obtained, for the purpose of conducting researches on the amount of solar heat and its absorption in the atmosphere, and related questions. The first measurements by the Weather Bureau of solar radiation received at the surface of the earth were taken with one of these instruments at Asheville and Black Mountain in North Carolina from November 10, 1902, until March 26, 1903, by H. H. Kimball (Mo. WEA. REV., 31: 320–334, 1903), although the instrument had previously been used during 1901–02 at Providence, R. I., under the direction of Carl Barus (Mo. WEA. REV., 31: 275–280, 1903; cf. *Rept. Chief of Weather Bureau*, 1902–1903, p. xix). Observations were then continued at Washington, D. C. (*Bull. Mt. Weath. Obs.*, 3: 69–126, 1910).

When the Mount Weather Observatory was established, provision was made for a comprehensive program of solar observations; pyrheliometric measurements were begun there on September 21, 1907. Meanwhile, polarimetric observations had also been commenced at Washington. This earliest work is summarized in *Bull. Mt. Weath. Obs.*, 1: 82–93, 207–231, 1908; 2: 55–65, 214–224, 1909–10; 3: 69–126, 1910; 5: 295–312, 1913; *Jour. Frank. Inst.*, 171: 333–344, 1911; Mo. WEA. REV., 42: 474–487 and 650–653, 1914; 43: 100–111, 1915. As the desirability of expanding the work became apparent, additional stations were occupied, improved instrumental equipment obtained, and further types of observations introduced. The first new stations added were at Madison, Wis., where observations were begun on July 19, 1910 (*Bull. Mt. Weath. Obs.*, 5: 173–183, 1912, and Mo. WEA. REV., 44: 8–12, 180–181, 1916, which summarized the data for 1910–15); and at Lincoln, Nebr., November 10, 1911 (Mo. WEA. REV., 44: 5–8, 1916, with data for 1911–1915). Observations at Mount Weather were discontinued at the end of September 1914, and the equipment transferred to a station at American University, Washington, D. C. The data obtained at Mount Weather and Washington in 1914–15 were published in the Mo. WEA. REV., 42: 138–141, 310–311, 520, 648–649, 1914; 43: 112–113, 1915, and monthly thereafter; data from Santa Fe are given in the Mo. WEA. REV., 43: 439–443, 590–591, 1915. Since January 1916, data for all stations have been published monthly in the REVIEW. The Santa Fe station was discontinued in March 1922.

The data which have been accumulated during the continuous observing program that has since been maintained at a growing network of stations, and the results of investigations based on these data, are of fundamental importance in a wide range of meteorological, oceanographic, physical, engineering, agricultural, biological, and medical problems (*cf.* Mo. WEATH. REV., 48: 18–24, 1920); they have found extensive application, both in practical work and in scientific research, and there has always been a demand for further extension of the program:

Sunshine data have long been recognized as an essential part of a complete climatological record.[1] Pyrheliometric records of total solar and sky radiation received on a horizontal surface are correspondingly of still more value than the records obtained with ordinary sunshine recorders which merely indicate when the direct rays of the sun reach the surface of the earth with an intensity sufficiently great to actuate the instrument.

A knowledge of both the amount of solar radiation that is received at the earth and also its distribution during the growing season is important to horticulturists, botanists, and plant physiologists. With growing appreciation of this fact, the number of universities and other institutions that maintain stations to determine the amount of solar and sky radiation for use in their own researches, and who cooperate with the Weather Bureau by forwarding their data, is increasing yearly. An interesting example of the application of such data in agriculture is provided by the case of a large sugar-beet company which operated at a loss near the Great Lakes some years ago, because of the excessive cost of processing fibrous beets with low sugar-content. Belatedly learning the cause of their failure, they removed their plant to Idaho where the greater radiation receipt during the growing season enables them to operate profitably because their beets now contain sufficient sugar. Their former location is totally unadapted for this particular crop. Examples of recent researches which involve solar radiation as a direct factor are those of Johnston[2] on the correlation of plant growth with the components of solar radiation; of Meier,[3] who has investigated the effects of different wave-lengths of radiation on green algae; of Burk and Lineweaver,[4] who have unravelled many of the mysteries of photosynthesis; of Flint and McAlister,[5] who have studied the effect of solar radiation in promoting germination in seeds; and many others.

Solar radiation data likewise find extensive application in the heating and air conditioning industries,[6] in illuminating engineering,[7] and in connection with studies of evaporation for various scientific and civil engineering purposes.[8]

It is not inconceivable that in the future when natural fuel resources become depleted, solar energy may be directly used on a large scale for heat and power; it has already been utilized for these purposes to a limited extent.[9]

SOLAR RADIATION INTENSITIES BEYOND THE LIMITS OF THE ATMOSPHERE

A complete study of solar radiation involves, first, the study of the sun itself—physical conditions throughout the sun, genesis of solar energy, properties of the emitted radiation, and their relations to other solar phenomena—which lies in the domain of astrophysics; second, the determination of the amount of radiation emitted by the sun, and its intensity distribution over the outer limits of the appreciable atmosphere of the earth; and third, the investigation of the depletion of the radiation while traversing the atmosphere, and the resultant geographical intensity distribution at the surface of the earth.

The immediate interest of the meteorologist is in the dynamic and thermodynamic effects of the energy trans-

[1] See Joseph B. Kincer, Sunshine in the United States, Mo. WEA. REV., 48: 12–17, 1920; R. DeC. Ward, Bibliographic Note on Sunshine in the United States, Mo. WEA. REV., 47: 794–5, 1919. U. S. Depart. of Agric., *Atlas of American Agriculture*, Washington, 1936.

[2] Earl D. Johnston, The Functions of Radiations in the Physiology of Plants. *Smith. Misc. Coll.*, v. 87, No. 14, 1932.

[3] Florence E. Meier, Effects of Intensities and Wave-Lengths of Light on Unicellular Green Algae. *Smith. Misc. Coll.*, v. 92, No. 6, 1934.

[4] Dean Burk and Hans Lineweaver, The Minimum Kinetic Mechanism of Photosynthesis, *Nature*, 135: 621, 1935.

[5] L. H. Flint, The Action of Radiation of Specific Wave-Lengths in Relation to the Germination of Light-Sensitive Lettuce Seed. *Comptes rendus de l'Association Internationale d'Essais de Semences*, No. 1. Copenhagen, 1936.

[6] See, e. g., the applications discussed in *Trans. Amer. Soc. Heating and Vent. Eng.*, 36: 137, 1930; 38: 231, 1932; 40: 101, 1934.

[7] The volumes of the *Trans. Illum. Eng. Soc.* contain a number of papers on this subject. E. g., the data are of great value to architects and others in designing window space in schools, factories, etc., to secure adequate lighting and, in many instances, insure compliance with state laws. *Cf.* Kimball and Thiessen, Mo. WEA. REV., 45: 205–207, 1917, and Kimball, Mo. WEA. REV., 42: 29–35, 1914, on the influence of city smoke on daylight illumination.

[8] B. Richardson, Evaporation as a function of insolation, *Trans. Amer. Soc. Civ. Eng.*, 95: 996–1019, 1931. G. F. McEwen, Heating and cooling of water surfaces, Mo. WEA. REV., 56: 398–399, 1928.

[9] See A. S. E. Ackermann, The Utilization of Solar Energy, *Jour Roy. Soc. of Arts*, April 30, 1915; rep. in *Ann. Rept. Smiths, Inst.* for 1915. Some recent experiments on the utilization of solar energy are described in *Bull.* 602, College of Agriculture, Berkeley Agric. Exp. Sta.; *Scientific American*, April 1936, p. 197; *Science*, Oct. 19, 1934 (Science News, p. 8); *Annals Astrophys. Obs.*, Smiths. Inst., v. 4, ch. 9.

formations and energy distribution which result from reflection, scattering and absorption of radiation in the atmosphere and at the surface of the earth. The Weather Bureau has therefore confined its solar radiation studies to measurements of the amount that reaches the surface of the earth and investigations of closely related phenomena.

The determination of the total intensity and spectral energy distribution of solar radiation at the outer limit of the appreciable atmosphere has been the principal work of the Astrophysical Observatory of the Smithsonian Institution.[10] The rate at which solar radiant energy is received outside the atmosphere on a surface *normal* to the incident radiation, at the earth's mean distance from the sun, is called the *solar constant;* the value of the mean solar constant obtained by the Astrophysical Observatory, viz, 1.94 gram calories per square centimeter per minute, has been almost universally adopted, and has been used in all the Weather Bureau computations.

The rate at which direct solar radiant energy is received on a *horizontal* surface will here be called the insolation (this term is also used in other senses by different writers); it depends upon (1) the solar constant, (2) distance from the sun, (3) inclination of the incident rays to the horizontal, as determined by latitude, time of year and time of day, and (4) depletion to which the radiation has been subjected during passage through the atmosphere. When the solar constant is known, the determination of the distribution of insolation outside the atmosphere, by latitude and time of year, is a simple problem in mathematical astronomy,[11] and is of fundamental importance to physical meteorology.

As radiation passes through the atmosphere, it is in general divided into three parts: (1) One part, almost unchanged in wave length, is turned aside from the direct beam, and scattered in practically all directions; (2) another part is absorbed, i. e., changed almost entirely into heat energy; (3) the remainder is propagated unchanged in wave length.

An exact mathematical theory has been formulated for the general nonselective scattering (molecular diffraction) by the permanent gases of the atmosphere, from which the transmission coefficients, sky illumination and sky color may be deduced; [12] but the nonselective scattering associated with water vapor exhibits anomalies. Selective absorption by water vapor, carbon dioxide, ozone, and oxygen, and the effects of dust and other foreign material in the air are difficult to treat theoretically, but have been extensively investigated by observation and experiment. (See fig. 21.)

From the known intensity distribution of solar radiation outside the atmosphere,[11] the distribution of insolation at the surface of the earth could be computed if the transmission of the atmosphere could be determined. In general, only the part of the transmission coefficient depending on molecular scattering by the permanent gases can be calculated with certainty from physical theory. The depletion from scattering and absorption by water vapor, and the effects of dust, etc., may be obtained more or less accurately from relations that have been established by observation, but in practice the distribution of water vapor and dust throughout the depth of the atmosphere and their variations with time are not usually known with any completeness. Estimates of the radiation receipt that may be expected from sun and sky at a given locality may be made when climatological data are available, especially if there is a pyrheliometric station in the same general region, but they are inevitably subject to considerable uncertainty; only direct observations can provide reliable values of the radiant energy actually received (*cf.* Mo. WEA. REV., 62: 282, 1934).

INSOLATION AT THE SURFACE OF THE EARTH

The solar radiation observational program conducted by the Weather Bureau has been devoted principally to regular pyrheliometric measurements of the intensity of solar radiation at normal incidence, and to continuous registration of the total solar and sky radiation that is received on a horizontal surface. Occasional measurements of sky polarization are included. The determination of atmospheric water vapor content and turbidity is also now a regular part of the observations. Summaries of all these data are published monthly in the REVIEW. Registrations of the visible component and of the ultraviolet component have recently been initiated at the Washington, D. C., station. From time to time, photometric and nocturnal radiation measurements have been conducted; and various miscellaneous studies, such as investigations of atmospheric dust, have been made. A number of summaries of the data obtained, together with several extended investigations based on these data and pertaining both to theoretical meteorology and to practical problems, have appeared in the MONTHLY WEATHER REVIEW and elsewhere during the past 20 years:

General introductory summaries of the subject as a whole are provided by H. H. Kimball, Solar Radiation and its Role (ch. 3 of *Physics of the Earth—III: Meteorology*, National Research Council Bulletin 79, Washington 1931); H. H. Kimball, Solar Radiation as a meteorological factor, *Reviews of Modern Physics*, 4: 259–277, 1932, and Mo. WEA. REV., 59: 472–479, 1931; H. H. Kimball and I. F. Hand, Intensity of solar radiation as received at the surface of the earth (in Nat. Res. Counc., *Biological Effects of Radiation*, pp. 211–226, New York, 1936), abst. in Mo. WEA. REV., 63: 1–4, 1935; H. H. Kimball, Amount of solar radiation that reaches the surface of the earth on land and sea, Mo. WEA. REV., 56: 393–399, 1928. (See also U. S. Weather Bureau, *Circular Q*, Pyrheliometers and Pyrheliometric measurements.) A brief account of the general principles of pyrheliometry is given by Kimball, *Bull. Mt. Weath. Obs.*, 3: 72–85, 1910.

Pyrheliometric measurements in most countries are reduced to the Smithsonian Scale of Pyrheliometry of 1913 (C. G. Abbot and L. B. Aldrich, Smithsonian Pyrheliometry Revised, *Smith. Misc. Coll.*, Vol. 60, No. 18, 1913). The Angström compensation pyrheliometer,[13] adopted as the standard by the Meteorological Conference at Innsbruck in 1906 and later in the same year by the Solar Physics Union at Oxford, is still accepted as the standard by a few countries in the Eastern hemisphere, although in many instances the ratio, "Smithsonian Standard/Angström Standard=1.035" has been applied to convert

[10] See *Annals* of the Astrophysical Observatory of the Smithsonian Institution, vols. 1–5. Washington, 1900–1932.

[11] See A. Angot, Recherches théoriques sur la distribution de la chaleur à la surface du globe, *Ann. Bur. Cent. Mét.*, mémoires de 1883, Paris, 1885. Wm. Ferrel, Temperature of the Atmosphere and Earth's Surface, *Prof. Papers of the Signal Service*, No. XIII, 1884. M. Milankovitch, *Théorie mathématique des phénomènes thermiques produits par la radiation solaire*, Paris, 1920. F. Baur und H. Philipps, *Gerlands Beiträge zur Geophysik*, 42: 160–207, 1934. *Cf.* W. J. Humphreys, *Physics of the Air*, 2d ed., pp. 78–84; *Smith. Met. Tables*, 5 ed., tables 98–99. See curve 1 in fig. 20.

[12] See W. J. Humphreys, *Physics of the Air*, 2 ed., pp. 537–546; L. V. King, On the scattering and absorption of light in gaseous media, with applications to the intensity of sky radiation, *Phil. Trans.*, A212: 375–434, 1913. F. E. Fowle, The atmospheric scattering of light. *Smith. Misc. Coll.*, Vol. 69, No. 3, 1918.

[13] Knut Ångström. The Absolute Determination of the Radiation of Heat with the Electric Compensation Pyrheliometer, and Examples of the Application of this Instrument. *Astrophys. Jour.*, 9: 332–346, 1899.

Ångström measurements to the Smithsonian scale.[14] In 1934, the Smithsonian Institution announced [15] that recent standardization tests lead to the conclusion that their former scale of pyrheliometry is about 2.3 percent high. Because of the great mass of pyrheliometric data that have been accumulated, it has been thought best to adhere to common practice and continue the use of the former scale; this has been done in the case of all pyrheliometric values herewith. The question of standard pyrheliometric scales is still under investigation by the International Meteorological Committee.

One gram calorie per square centimeter per minute is the unit in general use for nearly all pyrheliometric work. For the convenience of engineers and others who may wish to convert to other units, the following equivalents are given:

$$\begin{aligned} 1 \text{ g. cal.} &= 0.0039685 \text{ B. T. U.} &&= 4.186 \text{ joules} \\ &= 3.0874 \text{ ft. lb.} &&= 0.42685 \text{ kg m} \\ &= 1.5593 \times 10^{-6} \text{ HP. hour} &&= 0.0011628 \text{ watt-hours} \end{aligned}$$

During an average clear day in midsummer at Washington, D. C., about 1,000 kilowatt-hours of solar energy is received on each square dekameter—about the area occupied by an average eight-room house. Yet only 1 part in 2,200 million of the total energy radiated from the sun is intercepted by the entire earth.

Pyrheliometric Stations

The number of pyrheliometric stations is gradually increasing, not only in the United States but also throughout the world. In 1927–30, a list of pyrheliometric stations over the globe, with a bibliography of available data and a summary of the measurements, was compiled by Kimball.[16]

Table 1 gives information about the solar radiation stations which are maintained by, or cooperate with, the Weather Bureau. (See fig. 1.) A station at Athens, Ga., is also in prospect.

American University is about 3 miles northwest of the Central Office of the Weather Bureau in Washington, 5½ miles northwest of the United States Capitol and 1½ miles northwest of the Naval Observatory. There are no manufacturing plants within 3 miles of the University, but suburban development has gradually increased atmospheric pollution by smoke. During recent years, the rapid growth of trees close to the observing station has interfered to a slight extent with normal-incidence measurements at low solar altitudes; otherwise the site is considered as good as could be obtained within the District of Columbia, chiefly because of its high elevation and its location in the windward quarter of the city.

At Madison, Wis., the pyrheliometer is mounted on top of the instrument shelter on the roof of North Hall, University of Wisconsin, which is located on a bluff a short distance from the south shore of Lake Mendota. Most of the manufacturing establishments are in the eastern part of the city, but some contamination results from the university heating plant and also from the rapidly growing suburban development and the railroad lines adjoining the campus.

At Lincoln, Nebr., the radiation apparatus is located on the farm campus of the State University, 2½ miles northeast of the business section of the city. With a west or northwest wind the atmosphere is very clear; but with winds from other directions, smoke from railroads and industrial plants often depletes solar radiation receipt.

Blue Hill Observatory of Harvard University is located on the highest point of a long ridge 10 miles south of Boston; and little trouble is experienced from smoke, although occasionally with a north wind a slight smoke effect from the city is noticeable.

The station at Chicago is located in Rosenwald Hall on the campus of the University of Chicago. For a large city, the instruments have excellent exposure. Although smoke is troublesome at times, considerably more radiation is received here than at the main office of the Weather Bureau in the Federal Building within the Loop.

The city of New York cooperates in the maintenance of Central Park Observatory, located at Seventy-ninth Street and Tranverse Road in the heart of the park. An ornate tower furnishes excellent exposure for the pyrheliometer; and here, as in Chicago, a comparatively free low horizon gives values representative of average large city conditions.

The pyrheliometer at Pittsburg was at first located on top of the Oliver Building, a tall skyscraper in the heart of the city. After a few years of record were obtained, the apparatus was removed to the airport in the suburbs in order to obtain the differential values between the city and its suburbs; later, this station was discontinued.

The station at Fairbanks, Alaska, latitude 64° 52′ N., is much the farthest north at which total solar and sky radiation measurements are made regularly. The nearest approach to it is the Union of Soviet Socialist Republics station at Sloutzk, latitude 59° 41′ N. A few observations of this character have been made in the past at Green Harbor, Svalbard, latitude 78° 00′ N.[17] The pyrheliometer at Fairbanks was mounted on a support 10 feet above the roof of the office building, and has an unobstructed exposure to the horizon in all directions.

The pyrheliometric station at San Juan, P. R., is the farthest south of any of the Weather Bureau stations. Here also the pyrheliometer is located on top of the building in which the Weather Bureau has its offices; and it has a good exposure, comparatively free from shading effects of nearby objects. Here cooperation exists between the Weather Bureau and the director of a medical research project carried on under the auspices of Columbia University.

The Mount Washington station, opened in December 1933, was maintained for a brief period through the cooperation of Harvard University. It had the highest elevation of any of the stations. However, the difficulties of maintaining pyrheliometric apparatus on this peak were so great that after intermittent records were obtained for a few months, the attempt was abandoned. Lightning and wind destroyed pyrheliometers in rapid succession.[18]

Of all the pyrheliometric stations from which records are now regularly tabulated in the REVIEW, the one maintained by the Bureau of Entomology at Twin Falls, Idaho, has the greatest altitude, 1,300 meters.

At Tulane University in New Orleans, the pyrheliometer is mounted on a platform 40 feet above sea level; it measures all the direct solar radiation except when the sun is very low, but considerable sky radiation fails to record because of the presence of nearby buildings and trees above the horizon line. The hourly values are therefore reduced by a small but known amount.

At the Scripps Institution of Oceanography, La Jolla, Calif., the Weather Bureau type of thermoelectric pyrheliometer first in use gradually became defective. The recorded values during the deterioration period gradually decreased; and because of the impracticability of determining with accuracy the true values of radiation during that period, a new set of normals has been started with September 1935, which include only the values obtained since the installation of a new hermetically sealed pyrheliometer. This instrument is mounted on top of a water tank, where it has free exposure to both the sun and sky, except for hills in the East which cut off early morning direct radiation from the sun; however, early morning fogs prevail in this immediate section at certain seasons of the year.

For some years, the University of Florida, located at Gainesville, furnished data. A Moll thermopile [24] recording on a Richárd microammeter provided the records; both instruments had been calibrated by the Weather Bureau. Only meager information is available concerning the exposure, except that it is known the receiving unit had a comparatively free horizon.

Special stations have also been temporarily occupied from time to time; see, e. g., H. H. Kimball, Observations on the increase of insolation with elevation, *Bull. Mt. Weath. Obs.*, 6: 107–110, 1914.

The radiation normals at a given station that is free from local influences, such as city smoke, are probably fairly representative for similar altitudes above sea level in the same general region. The observations from the preceding stations may therefore be used, together with

[14] Dorno. Tägliche, jährliche und säkulare Schwankungen der Sonnenstrahlung in Davos. (Rapport fait à la 1re Conférence internationale de la Lumière, Lausanne-Leysin, 10–13, Sept. 1928.) *Cf.* Mo. WEA. REV., 47: 798–799, 1919.

[15] C. G. Abbot and L. B. Aldrich. The Standard Scale of Solar Radiation. *Smith. Misc. Coll.*, Vol. 92, No. 13, 1934.

[16] H. H. Kimball, Measurements of Solar Radiation Intensity and Determinations of its Depletion by the Atmosphere with Bibliography of Pyrheliometric Measurements, Mo. WEA. REV., 55: 155–169, 1927; Measurements of solar radiation intensity and determinations of its depletion by the atmosphere, Mo. WEA. REV., 58: 43–52, 1930. Observations in Arctic regions are summarized by Kimball in Gerlands *Beiträge zur Geophysik*, 32: 100–105, 1931, and Mo. WEA. REV., 59: 154–157, 1931. From such observations as were available at marine stations, and from data on climatological conditions, Kimball has constructed charts of probable average solar and sky radiation received over the oceans at the times of equinoxes and solstices: Mo. WEA. REV., 56: 393–399, 1928, and 59: 478, 1931; *Rev. Mod. Phys.*, 4: 271–273, 1932; Nat. Res. Counc., *Physics of the Earth*—III, pp. 48–49.

[17] H. H. Kimball. Solar Radiation Intensities within the Arctic Circle. Mo. WEA. REV., 59: 154–157, 1931.

[18] *Cf.* B. Haurwitz. Total Solar and Sky Radiation on Mount Washington, N. H. Mo. WEA. REV., 65: 97–99, 1937.

[24] Ladislaus Gorczynski. Simple Instruments for Direct Readings of Solar Radiation Intensity from Sun and Sky. Mo. WEA. REV., 54: 381–384, 1926.

climatological data, as a basis for the preparation of charts of the approximate distribution of solar radiant energy over the country; in this way, Kimball in 1919 prepared, from data then available, tables and maps for the United States of average normal incidence intensities and their variation with altitude, and of average intensities and daily totals of combined solar and sky radiation on a horizontal surface and the illumination equivalents thereof (MON. WEA. REV., 47: 769–793).

Total Solar and Sky Radiation on a Horizontal Surface

Instruments for measuring the total solar and sky radiation that is received on a horizontal surface should conform closely to the following specifications if the results are to be comparable with those in general obtained elsewhere:

(7) The instrument should not reradiate to the sky.
(8) The receiving surfaces should be exposed to the entire sky hemisphere.
(9) The receiving surfaces should be flat.
(10) The hemispherical cover should be flawless, and of ample size to prevent "caustics" and shadow effects from striae.

With these requirements in mind, the Weather Bureau has adopted for its present standard the Eppley thermoelectric pyrheliometer (fig. 3), a modification of the original [19] Weather Bureau type. This instrument consists of two concentric circular rings of equal area, one blackened and the other white-coated. The hot junctions of a multiple-couple thermopile of gold-palladium and platinum-rhodium alloys are attached to the lower side of the black ring, and the cold junctions are fastened to the lower side

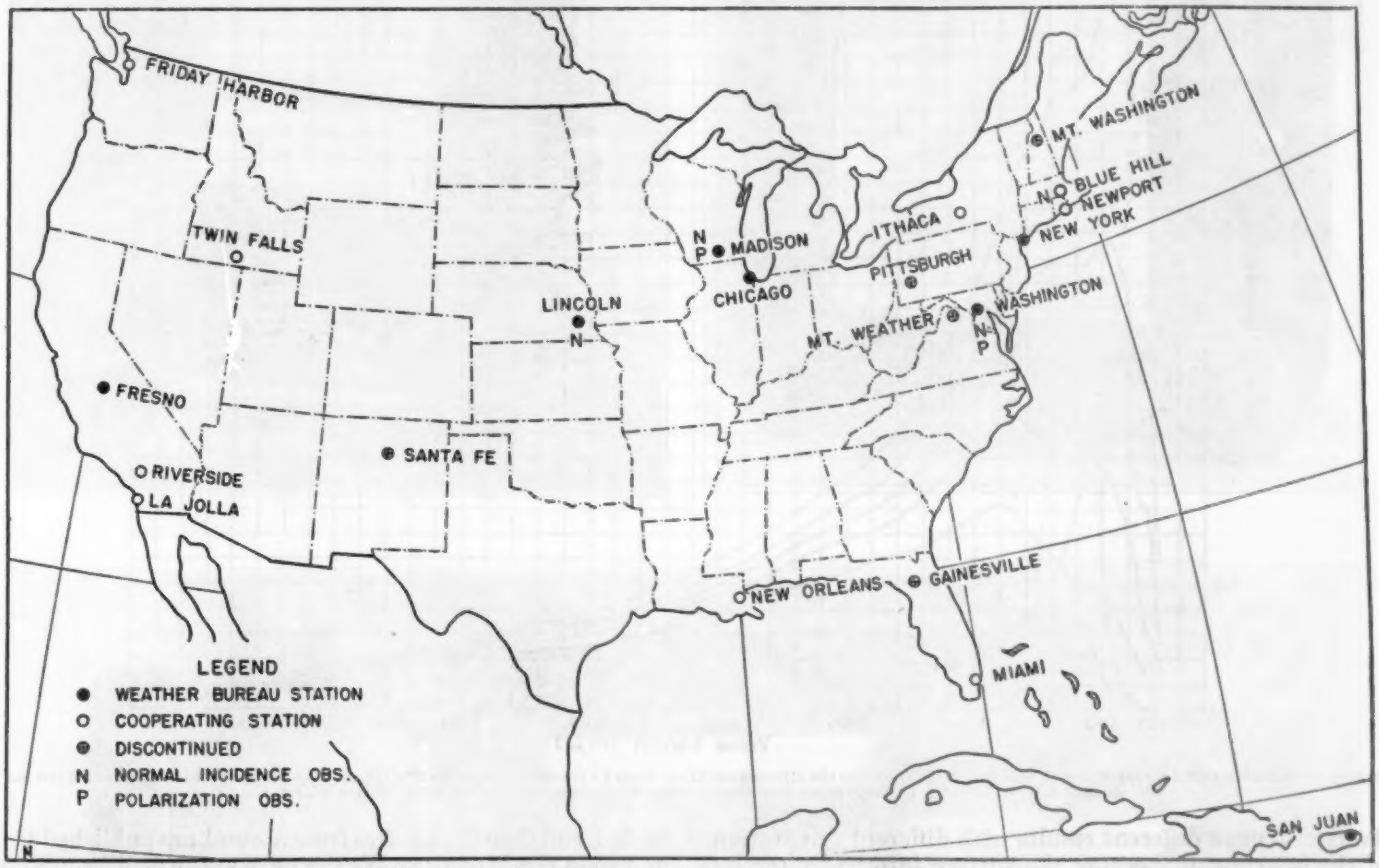


FIGURE 1.—Distribution of pyrheliometric stations in the United States (exclusive of Fairbanks, Alaska) which are maintained by, or cooperate with, the Weather Bureau. See table 1.

(1) They should be sensitive to radiation of wavelengths between 0.295μ and 2.5μ. (See fig. 2.)
(2) They should be proof against wind, weather, and moisture.
(3) The receiving surfaces should remain of constant sensitivity.
(4) The receiving surfaces must be nonselective in their reaction to radiation of different wave lengths.
(5) The instrument should be so designed that the reduction of its readings to gram-calories or other units will give results comparable with measurements taken elsewhere in accordance with standard pyrheliometric practice.
(6) The readings should not be influenced by temperature variations; that is, the sensitivity should be proportional only to the amount of incident radiation.

of the white ring; the differential in temperature between the two rings when radiation falls upon them then creates an e. m. f. that is very nearly proportional to the amount of radiation received. The rings are mounted horizontally in the center of a thin spherical glass-bulb which is sealed to prevent deterioration of the receiving surfaces and also to prevent moisture from condensing within. (Cf. U. S. Weather Bureau Circular Q.)

According to Stockbarger,[20] the glass used in the manufacture of Eppley pyrheliometers transmits 82 percent of the radiation at wave length 0.335 μ, 58 percent at 0.314 μ, and one third at 0.32 μ. Some radiation of wave length

[19] Herbert H. Kimball and Hermann E. Hobbs, A New Form of Thermoelectric Pyrheliometer, MO. WEA. REV., 51: 239-242, 1923. Also *Jour. Opt. Soc. Amer.*, 10: 365-368, 1925.

[20] On basis of tests made at the Massachusetts Institute of Technology, Cambridge, Mass., on Eppley pyrheliometer No. 41, January 1937.

0.27 μ, considerably shorter than any received at sea level, is transmitted by this glass. The amount of radiation below 0.3 μ received in cities is negligible in records of total solar and sky radiation; it is of great importance in connection with studies of antirachitic radiation, but measurements of it must be made by other means.

In addition to the Eppley pyrheliometer, various other types of instrument also have been, and in some cases still are, in use at many stations. At Miami, e. g., the Callendar electrical resistance pyrheliometer,[21] recording on an automatic Wheatstone bridge, is used and has the advantage of a quartz cover. Experience with the older types of Callendar receivers showed that caustics and striae caused, respectively, by internal reflection and flaws in the cover, were the source of some inaccuracies.[22]

meters [23] (fig. 4), that have a full-scale deflection of either 15 or 30 microamperes. Tulane University uses an Eppley receiver, but records the radiation with a portable Richárd microammeter.[24]

At Washington, Madison, and Lincoln, the e. m. f. generated by the thermopiles is recorded on Leeds and Northrup micromax potentiometers (fig. 4), which eliminate, or at least reduce to a minimum, errors arising from free-air and other temperature fluctuations.

Hourly radiation totals are obtained from the record sheets (fig. 5), by mechanical integration of the curves with a planimeter, and multiplication by an appropriate factor to reduce to gram calories.

The current weekly averages of daily totals of solar and sky radiation on a horizontal surface at the stations listed in

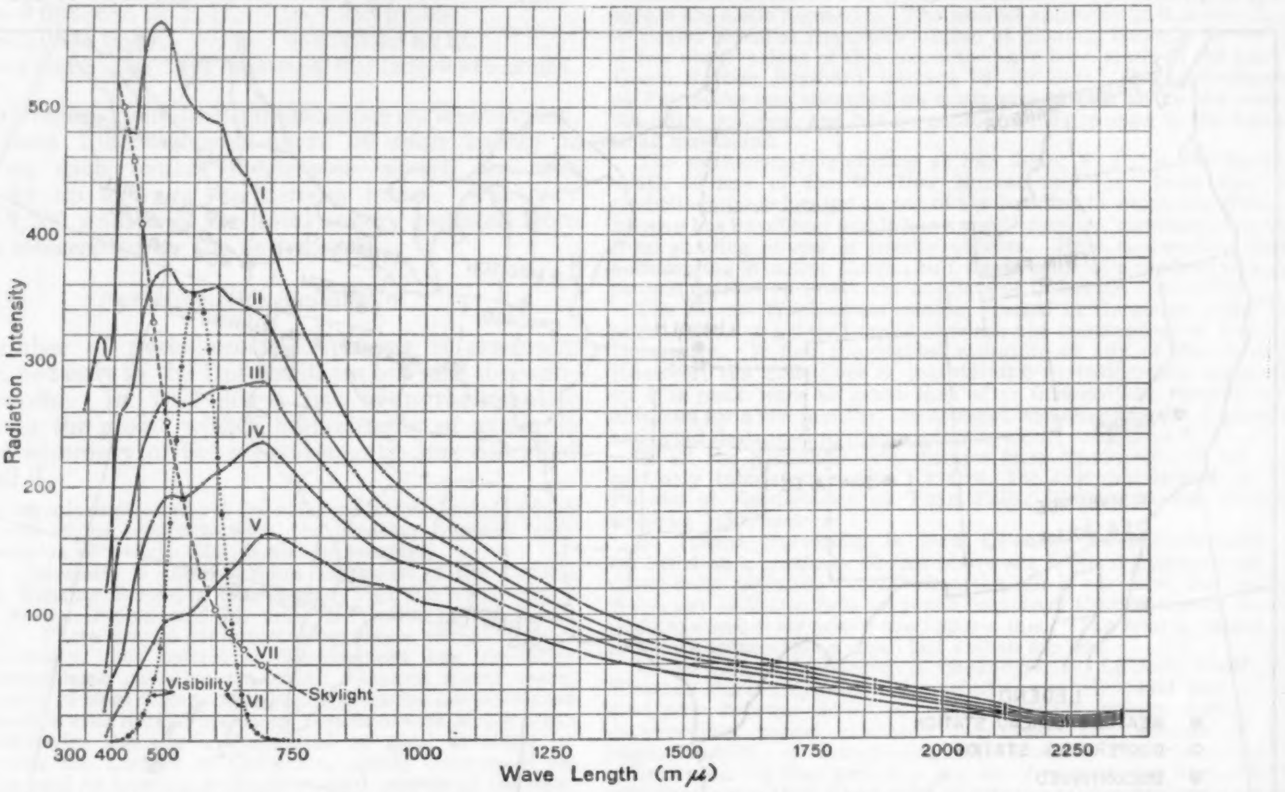


FIGURE 2.—Normal spectral energy curves of solar radiation: I, outside the atmosphere; II, air mass 1.1 (zenith distance, $z=25°$); III, air mass 2.0 ($z=60°$); IV, air mass 3.0 ($z=70.7°$); V, air mass 5.0 ($z=78.7°$); VI, visibility curve for solar radiation; VII, energy curve for sky light, Mount Wilson, Calif.

Tests also gave different results with different orientations of the instrument, because the surface formed by the imbedded wires and paint was not perfectly flat.

Pyrheliometers with spherical receiving surfaces have been suggested from time to time, but certain inherent difficulties of manufacture, and of interpretation of the records, have limited their use except for special purposes. They are, in fact, instruments for measuring normal incidence radiation and sky radiation simultaneously.

For the purpose of continuous registration, either recording potentiometers or microammeters may be used. Fundamentally, the potentiometric method is the more accurate, although the error in recording microammeters is reduced to a minimum by the addition of high resistance kept at a uniform temperature. At several stations Eppley pyrheliometers record on Engelhard microam-

table 1, and their departures from normal, are published each month in the MONTHLY WEATHER REVIEW. The original forms recording the values for each hour and each day at most of the stations are in the files of the Weather Bureau.

Table 2 gives the weekly and annual means for the periods of record of the daily total solar and sky radiation received on a horizontal surface at the 19 stations for which such data have been published in the REVIEW; table 3 gives the hourly means at Washington for each week and for the year. In figures 6 to 11, inclusive, are shown the daily averages for 16 stations, arranged in order of increasing latitude, together with a composite curve for all 16 stations, and curves giving daily maximum and minimum values at Washington. The influences of latitude and altitude should be noted. (See also fig. 20.)

In 1914, Kimball pointed out that in the data for Washington and Mount Weather there is evidence of a maxi-

[21] See Herbert H. Kimball, Total Radiation Received on a Horizontal Surface, Mo. WEA. REV., 42: 474–487, 1914, for a description of this instrument and its calibration. *Cf.* U. S. Weather Bureau Circular Q; and *Jour. Opt. Soc. Amer.*, 10: 363–365, 1925.

[22] Eric R. Miller. Internal Reflection as a Source of Error in the Callendar Bolometric Sunshine Recorder. Mo. WEA. REV., 43: 264–266, 1915.

[23] Circular Q, Weather Bureau; *Jour. Opt. Soc. Amer.*, 10: 367–368.

[24] Ladislaus Gorczyński. Simple Instruments for Direct Readings of Solar Radiation Intensity from Sun and Sky. Mo. WEA. REV., 54: 381–384, 1926.

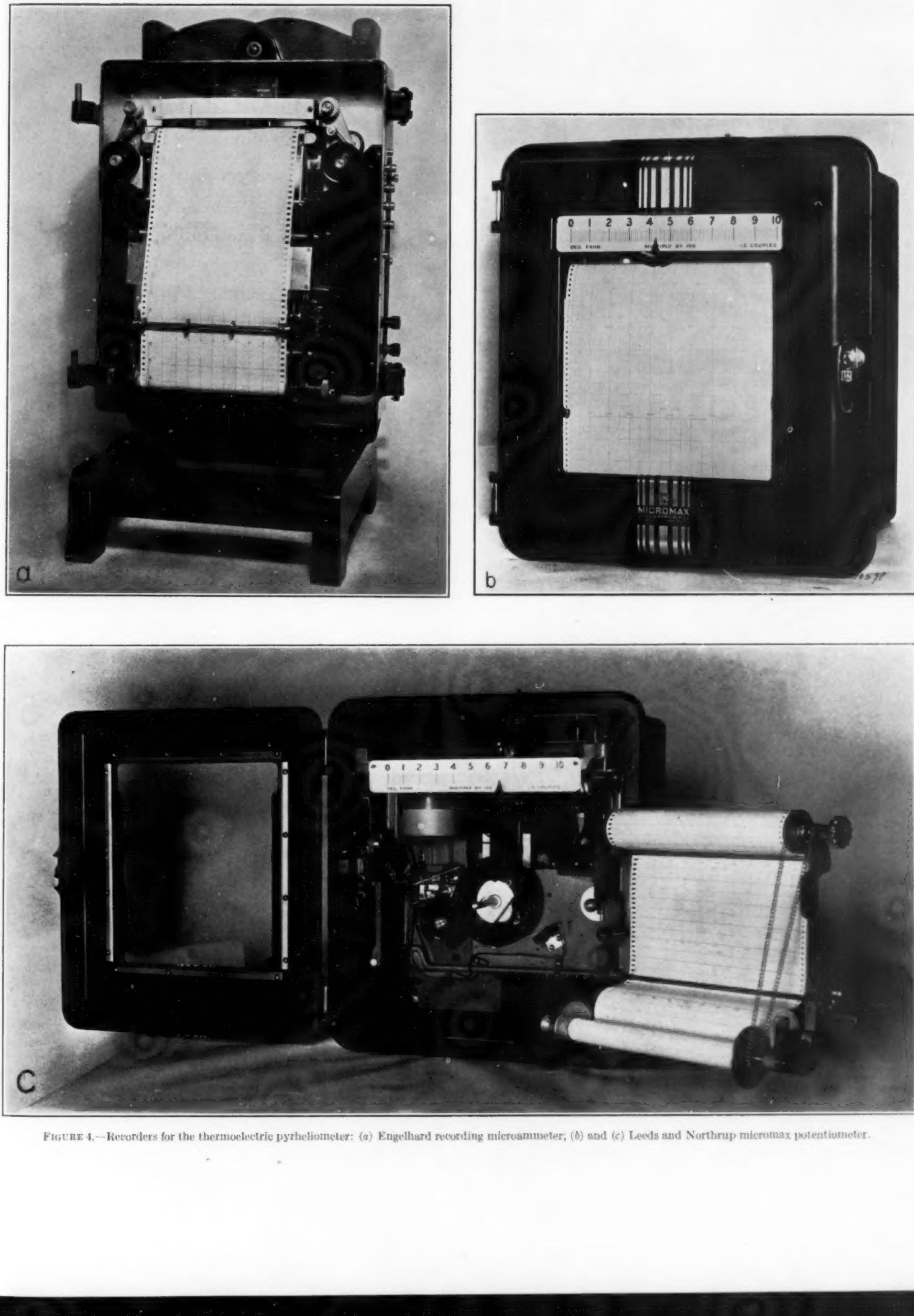


FIGURE 4.—Recorders for the thermoelectric pyrheliometer: (a) Engelhard recording microammeter; (b) and (c) Leeds and Northrup micromax potentiometer.

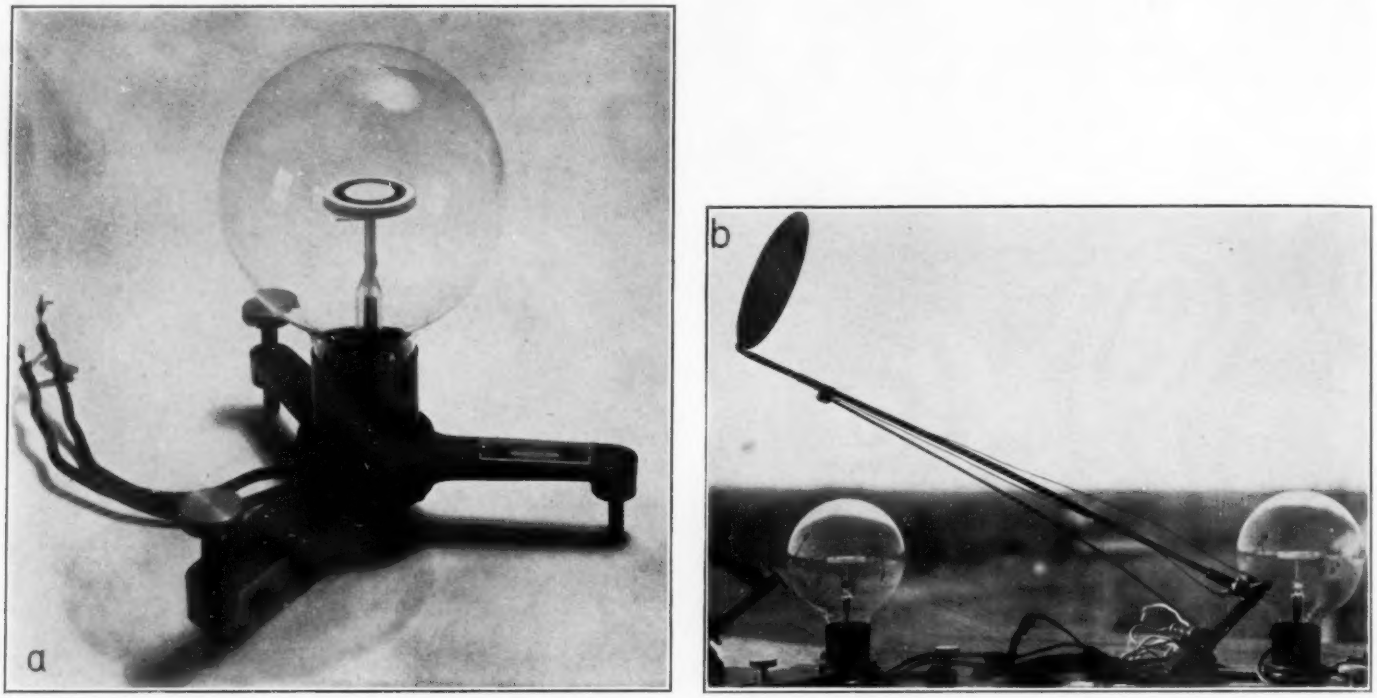


FIGURE 3.—Eppley thermoelectric pyrheliometer: (*a*) Receiving element and mounting; (*b*) occulting screen for intercepting direct solar beam.

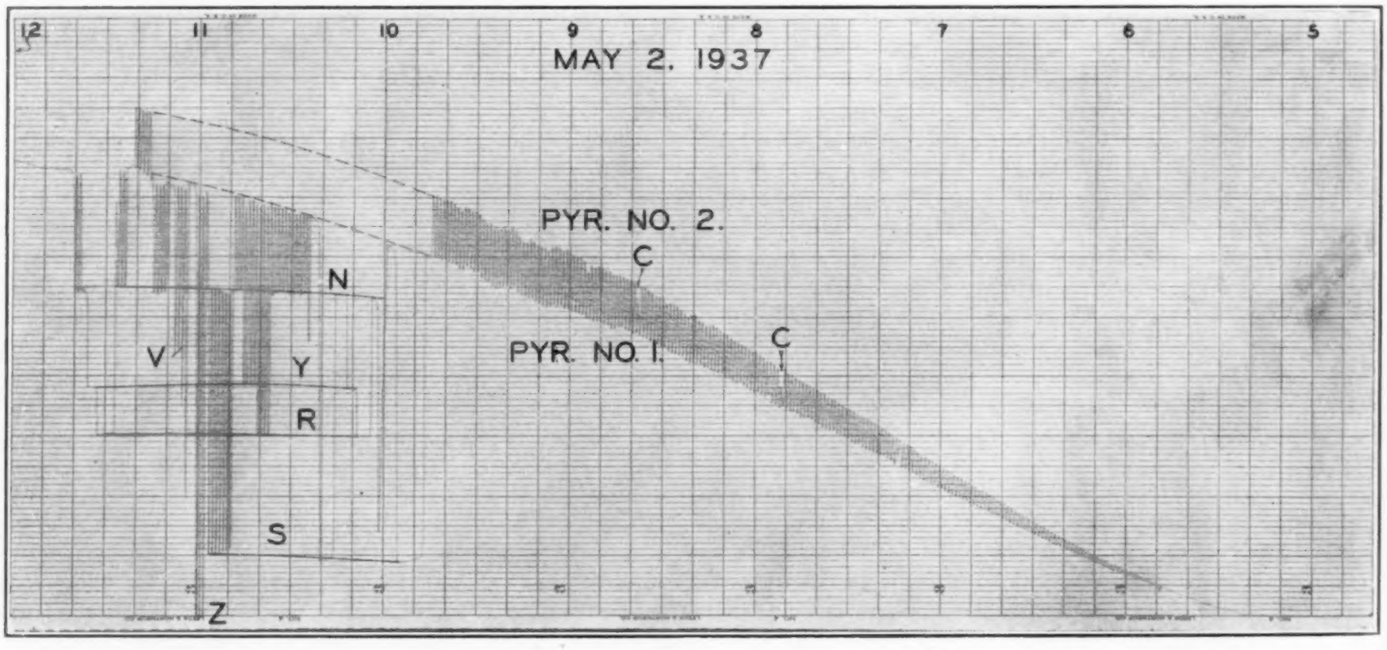


FIGURE 5.—Records of total solar and sky radiation on a horizontal surface made by two pyrheliometers operating simultaneously: The highest points on the oscillating curve are the readings of pyrheliometer No. 2, the lowest points those of pyrheliometer No. 1; instrument No. 2 was undergoing calibration. In addition, records of intensity at normal incidence, *N;* of intensity at normal incidence through color screens, *Y* and *R;* of sky radiation alone, *S;* and of the visible component alone (4,000 to 7,000 angstroms), *V*, have been taken at intervals on the same sheet. *Z* represents a check on the zero point of the vertical scale, and *C* shows irregular record made while the instrument automatically checked dry cells against a standard cell.

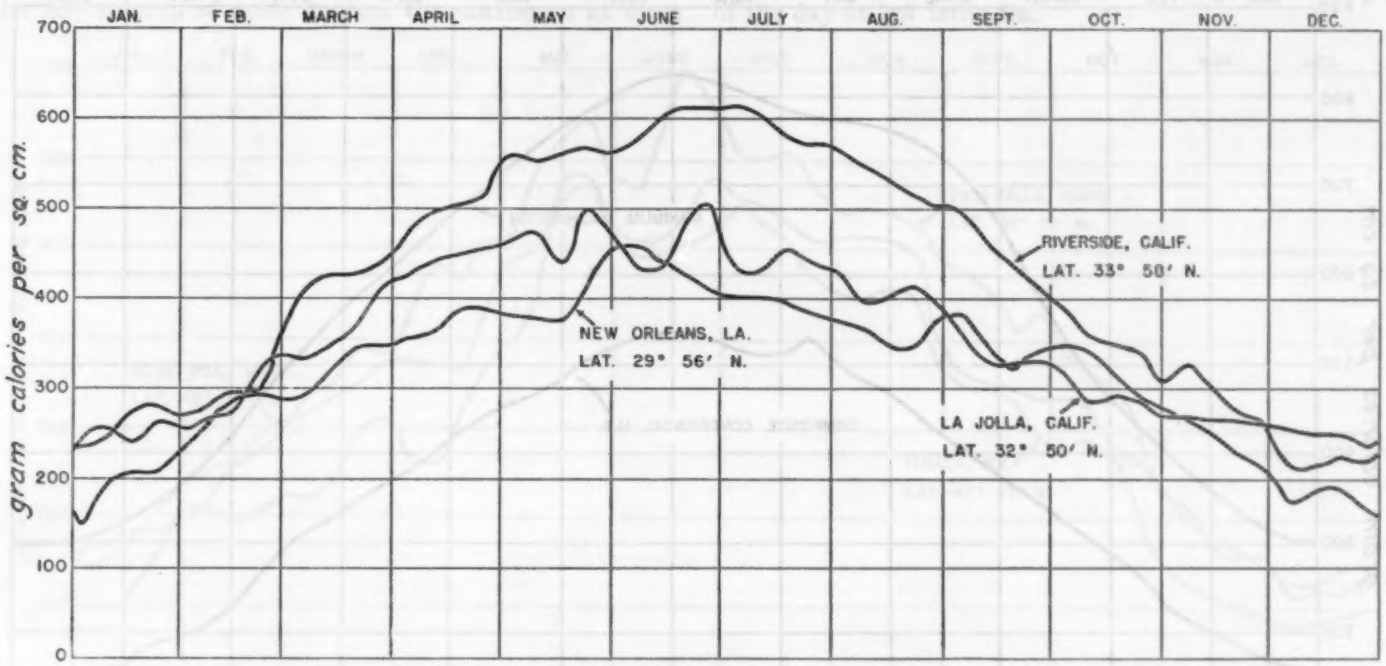


FIGURE 6.—Average daily total solar and sky radiation on a horizontal surface: New Orleans, La.; La Jolla, Calif.; and Riverside, Calif. See table 2.

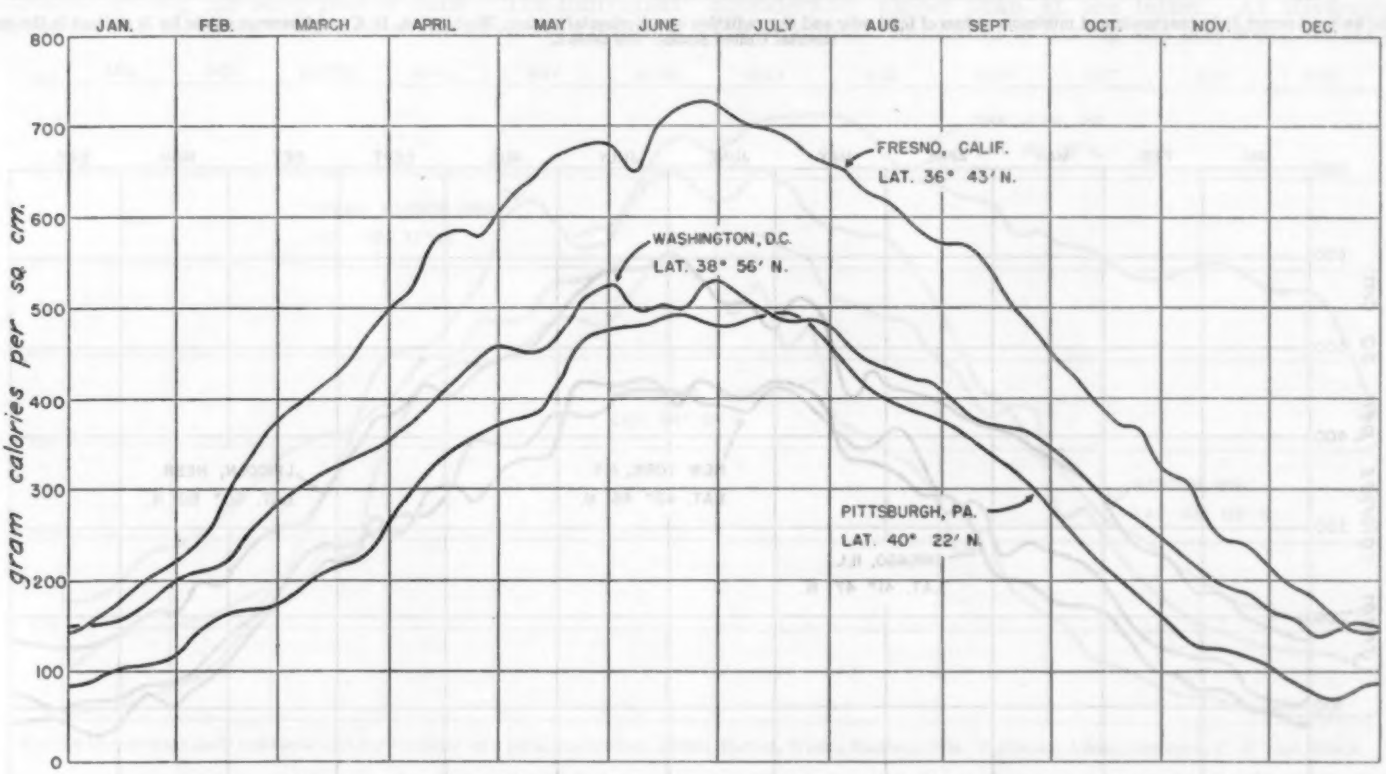


FIGURE 7.—Average daily total solar and sky radiation on a horizontal surface: Pittsburgh, Pa.; Washington, D. C.; Fresno, Calif. See table 2.

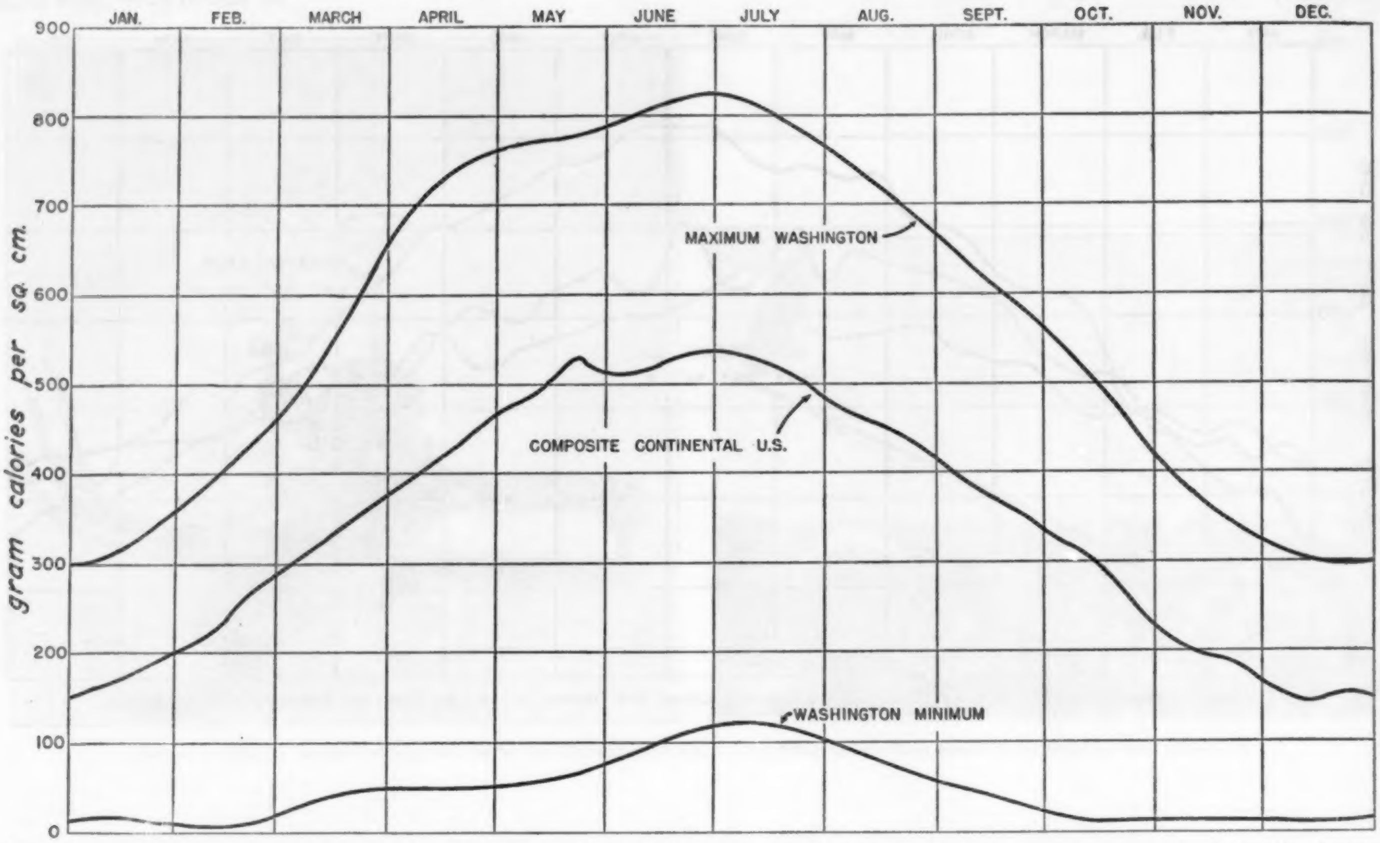


FIGURE 8.—Average daily maximum and minimum values of total solar and sky radiation on a horizontal surface, Washington, D. C.; and average values for 16 stations in the continental United States. See table 2.

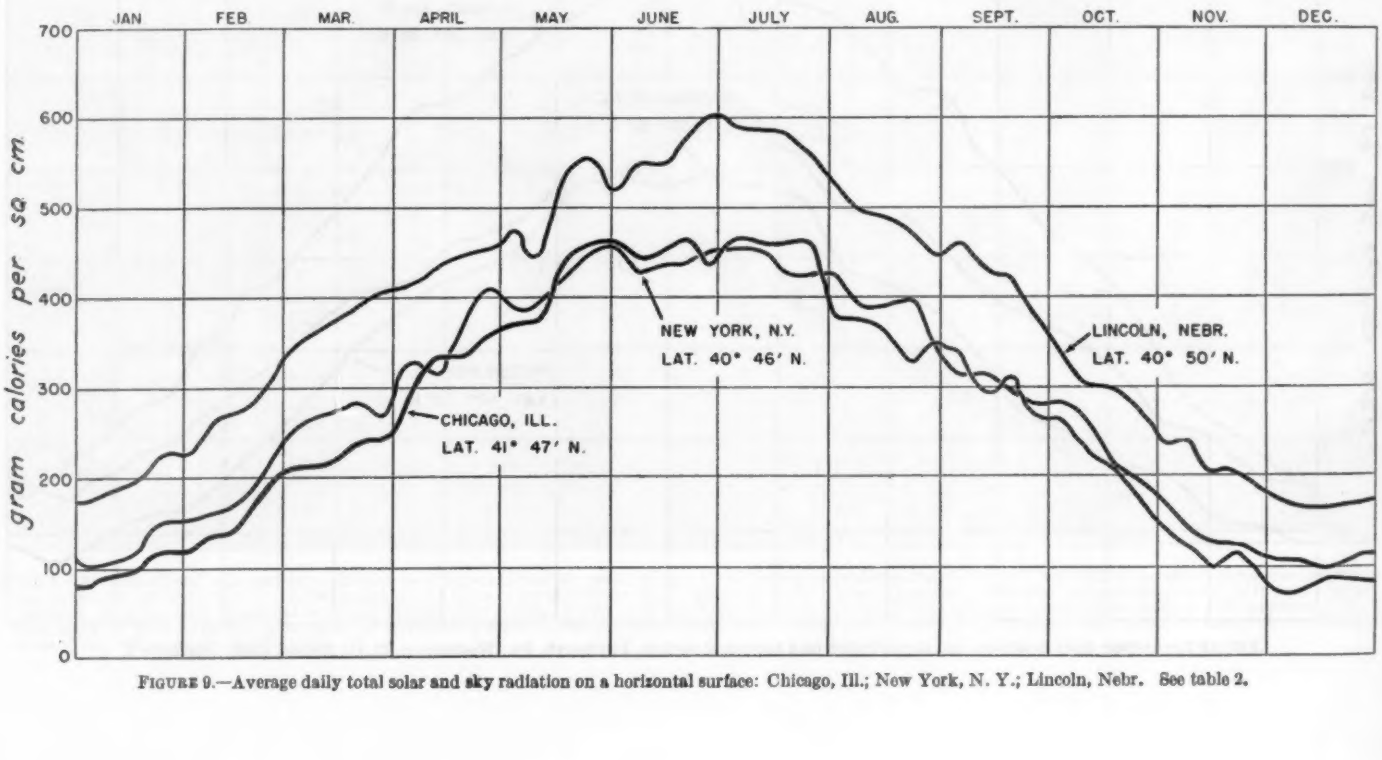


FIGURE 9.—Average daily total solar and sky radiation on a horizontal surface: Chicago, Ill.; New York, N. Y.; Lincoln, Nebr. See table 2.

mum of radiation in May, and of a secondary minimum in June or July, followed by a secondary maximum.[25] The more comprehensive data in the above curves and the last column of table 2 place the maximum at most

The difference between summer and winter values at low latitude stations is far less than at high latitude stations, because of the smaller seasonal range in the length of the day at low latitudes.

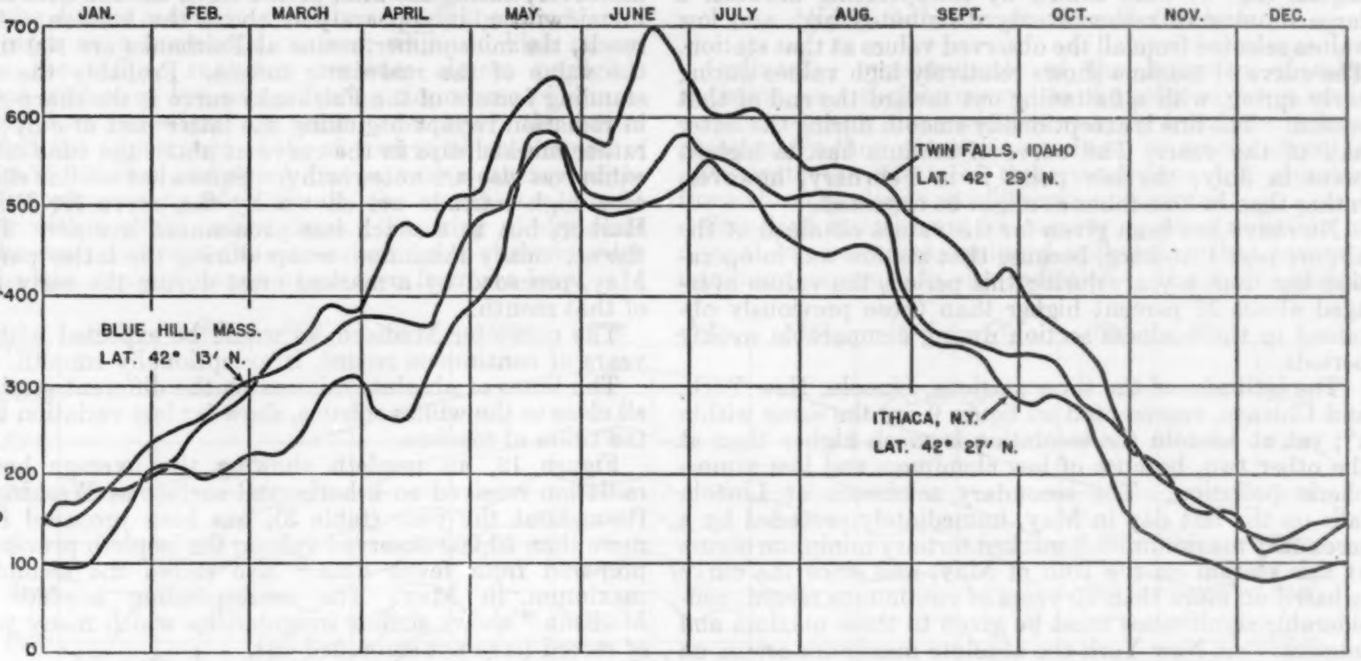


FIGURE 10.—Average daily total solar and sky radiation on a horizontal surface: Ithaca, N. Y.; Blue Hill, Mass.; Twin Falls, Idaho. See table 2.

stations during the last few days in June, with a secondary maximum shortly after the middle of May and a secondary minimum during the early part of June. The individual curves for the various stations show the secondary minima

Figure 6 shows that at Riverside, with consistently clearer skies than New Orleans, the insolation averages considerably higher than at the latter. At Riverside, the secondary minimum is during the last week in May;

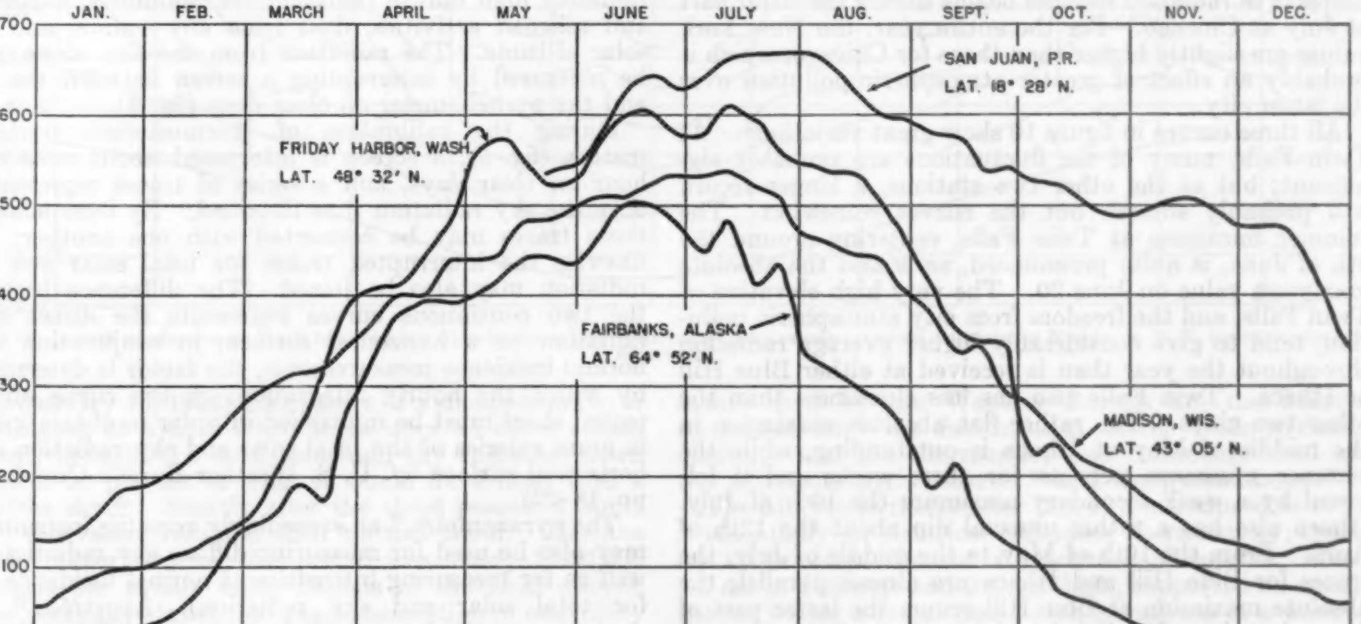


FIGURE 11.—Average daily total solar and sky radiation on a horizontal surface: Friday Harbor, Wash.; Madison, Wis.; Fairbanks, Alaska; San Juan, P. R. See table 2.

within 2 weeks of the mean, and in practically every case it is well defined; a study of the average cloudiness and average sunshine at these stations during the times of the secondary minima should prove informative.

[25] MO. WEA. REV., 43: 101, 1915.

but at New Orleans, the absolute maximum is during the first week in June. *Cf.* H. S. Mayerson and H. Laurens, *Total Solar Radiation at New Orleans*, MO. WEA. REV., 62: 281–286, 1934.

The La Jolla data must be used with the condition of the pyrheliometer, noted above, borne in mind; sufficient

time has not yet elapsed since the installation of a new pyrheliometer at that station to warrant publishing new normals.

The curves of maximum and minimum values at Washington (fig. 8) were drawn by interpolating between a large number of rather evenly distributed high and low values selected from all the observed values at that station. The curve of maxima shows relatively high values during early spring, with a flattening out toward the end of that season. The line is exceptionally smooth during the latter half of the year. The curve of minima has its highest point in July; the low point is in February, however, rather than in December as might be expected.

No curve has been given for the values obtained at the airport near Pittsburg, because that station was in operation less than a year; during this period, the values averaged about 25 percent higher than those previously obtained in the business section during comparable weekly periods.

The latitudes of the three stations, Lincoln, New York, and Chicago, represented on figure 9 are the same within 1°; yet at Lincoln the insolation is much higher than at the other two, because of less cloudiness and less atmospheric pollution. The secondary minimum at Lincoln falls on the last day in May, immediately preceded by a secondary maximum. A marked tertiary minimum occurs at this station on the 10th of May; and since the curve is based on more than 20 years of continuous record, considerable significance must be given to these maxima and minima. At New York the absolute maximum occurs on the last day of May, or at the same time as the summer minimum at Lincoln. During the spring in New York, the line is very wavy. At Chicago, the primary, secondary, and tertiary maxima are of about the same order of magnitude, and the summer minimum occurs at the time of the absolute maximum at Lincoln. A very marked decrease in radiation receipts begins during the latter part of July at Chicago. For the entire year, the New York values are slightly higher than those for Chicago, which is probably an effect of greater atmospheric pollution over the latter city.

All three curves in figure 10 show great variations. At Twin Falls, many of the fluctuations are probably significant; but at the other two stations, a longer record will probably smooth out the curves somewhat. The summer minimum at Twin Falls, centering around the 8th of June, is quite pronounced, as is also the absolute maximum value on June 20. The very high elevation of Twin Falls, and the freedom from city atmospheric pollution, tend to give considerably higher average radiation throughout the year than is received at either Blue Hill or Ithaca. Twin Falls also has less cloudiness than the other two cities. The rather flat absolute maximum in the middle of May at Ithaca is outstanding, while the summer minimum persists for three weeks and is followed by a weak secondary maximum the 10th of July. Ithaca also has a rather unusual dip about the 12th of April. From the 10th of May to the middle of July, the traces for Blue Hill and Ithaca are almost parallel; the absolute maximum at Blue Hill occurs the latter part of June, but is only slightly higher than the secondary maximum the 23d of May. *Cf.* B. Haurwitz, Daytime Radiation at Blue Hill Observatory in 1933, *Harvard Meteorological Studies*, No. 1, 1934.

The curves for the most northerly three stations and that for the most southerly station appear on figure 11. From less than a year's record, the curve for San Juan clearly illustrates the effect of the southerly latitude, both by the high midsummer values and by the relatively high winter values. At Fairbanks, radiation is recorded in midwinter during less than 4 hours of the day, while in midsummer the sun shines nearly 20 hours out of the 24; moreover, during the brief period when the sun does shine in midwinter, it appears just above the horizon. As a result, the midsummer means at Fairbanks are 100 times the value of the midwinter means. Probably the outstanding feature of the Fairbanks curve is the sharp drop in radiation receipt beginning the latter part of July; the rather marked dips in the curve at about the time of the equinoxes also are noteworthy. Somewhat similar effects of a high latitude are shown by the curve for Friday Harbor, but in a much less pronounced manner. Here the secondary minimum occurs during the latter part of May, preceded by a marked crest during the early part of that month.

The curve for Madison, as would be expected with 26 years of continuous record, is exceptionally smooth.

The times of absolute minima at the different stations, all close to the winter solstice, show far less variation than the times of maxima.

Figure 12, an isopleth showing the average hourly radiation received on a horizontal surface at Washington throughout the year (table 3), has been prepared from more than 50,000 observed values; the isopleth previously prepared from fewer data [25] also shows the secondary maximum in May. The corresponding isopleth for Madison [26] shows similar irregularities which many years of record have not smoothed out.

A considerable portion of the total incident solar radiation is in the form of diffuse radiation from the sky; in fact, on cloudy days all radiation necessarily is diffuse. The percentage of diffuse to total on clear days varies with the amount of dust, water vapor, and other foreign material in the atmosphere; the chief causes of proportionately high diffuse radiation are cloudiness, industrial and railroad activities, dust from any source, and low solar altitude. The radiation from the sky alone may be measured by intercepting a screen between the sun and the pyrheliometer on clear days (fig. 3).

During the calibration of thermoelectric pyrheliometers, (fig. 5), a screen is interposed about once each hour on clear days, and a series of traces representing only the sky radiation thus obtained. By interpolation, these traces may be connected with one another; and likewise the interrupted traces for total solar and sky radiation may also be joined. The difference between the two continuous curves represents the direct solar radiation on a horizontal surface; in conjunction with normal incidence measurements, the factor is determined by which the hourly integrations of the curve on the record sheet must be multiplied in order to obtain values in gram calories of the total solar and sky radiation on a horizontal surface (*cf.* U. S. Weather Bureau Circular Q, pp. 18–22).

The pyranometer,[27] an exceedingly versatile instrument, may also be used for measuring diffuse sky radiation (as well as for measuring intensities at normal incidence and for total solar and sky radiation). Ångström [28] has devised a special instrument for measuring sky radiation.

Table 4 has been prepared from a large number of diffuse radiation measurements and shows clearly the increase in the ratio of diffuse to direct solar radiation

[25] Mo. Wea. Rev., 43: 101, 1915.

[26] Arthur F. Piippo. Seventeen-Year Record of Sun and Sky Radiation at Madison, Wis. Mo. Wea. Rev., 56: 501, 1928.

[27] *Smith. Misc. Coll.*, Vol. 66, Nos. 7, 11; Vol. 69, No. 9; *cf.* Vol. 72, No. 13.

[28] Anders Angström. A New Instrument for Measuring Sky Radiation. Mo. Wea. Rev., 47: 795–797, 1919.

with increase in solar zenith distances (*cf.* Mo. Wea. Rev., 52:475, 1924). All values are with cloudless skies; on the relation of total radiation to cloudiness, see Mon. Wea. Rev., 47:780, 797, and *Quar. Jour. Roy. Met. Soc.*, 50:121–126. In cities, near the times of sunrise and sunset, the diffuse radiation actually exceeds the direct solar radiation on a horizontal surface; while on high mountains the diffuse radiation becomes almost negligible except with very low sun. During the course of atmospheric dust investigations some years ago [29] the writer studied the appearance of the sky when at an altitude of about 18,000 feet, and noted that on very clear days without interference by high clouds, the zenith was almost black with a slight indigo tinge. The ring of sky close to the sun's disk was also quite dark up to the very edge of the sun, a phenomenon never seen from sea level.

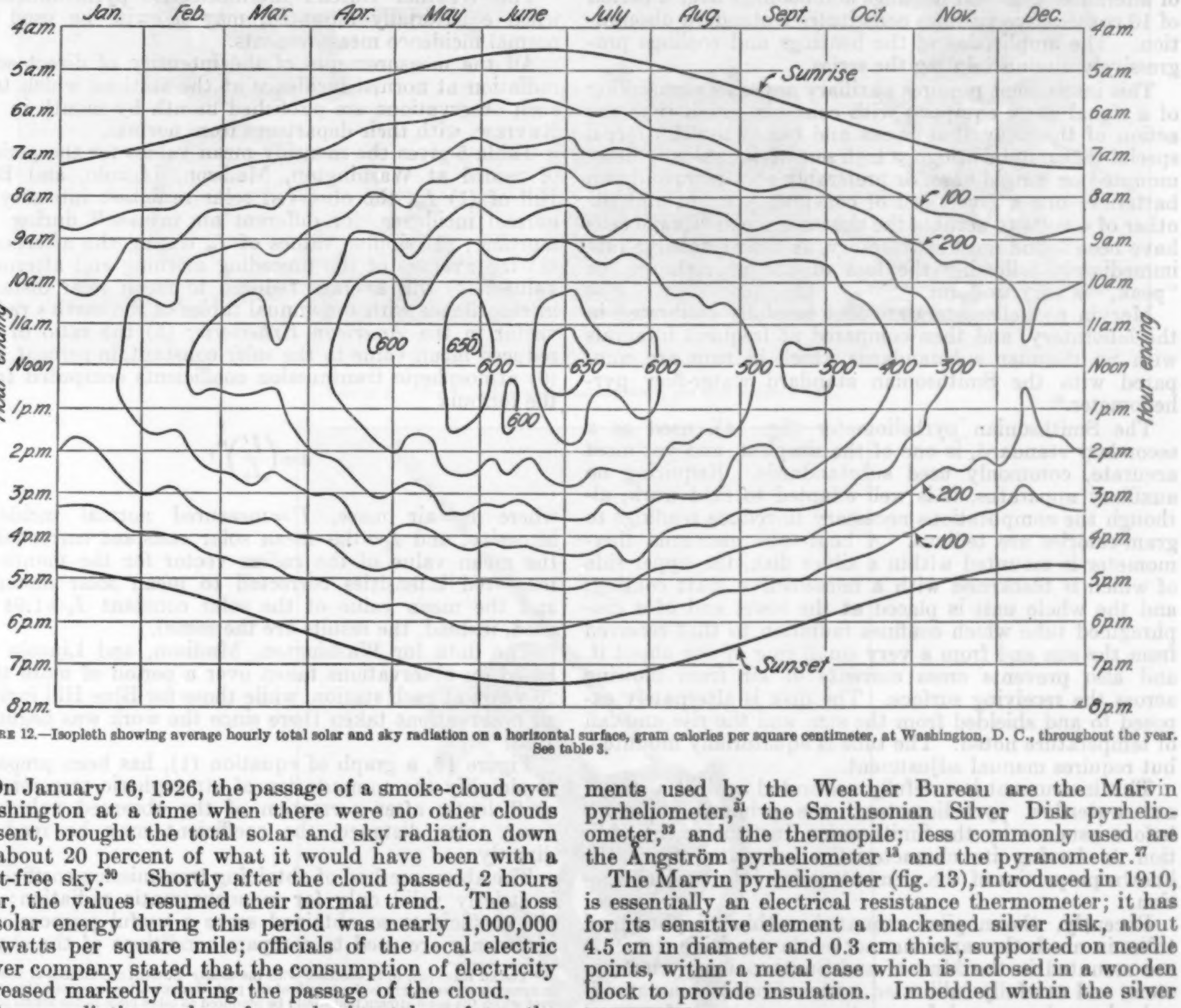


FIGURE 12.—Isopleth showing average hourly total solar and sky radiation on a horizontal surface, gram calories per square centimeter, at Washington, D. C., throughout the year. See table 3.

On January 16, 1926, the passage of a smoke-cloud over Washington at a time when there were no other clouds present, brought the total solar and sky radiation down to about 20 percent of what it would have been with a dust-free sky.[30] Shortly after the cloud passed, 2 hours later, the values resumed their normal trend. The loss of solar energy during this period was nearly 1,000,000 kilowatts per square mile; officials of the local electric power company stated that the consumption of electricity increased markedly during the passage of the cloud.

From radiation values for a horizontal surface, the values for a plane surface of any slope and orientation may be computed and are of considerable importance in many practical applications of solar radiation data. Methods of computation, and representative results, will be found, e. g., in Mo. Wea. Rev., 47:781–793, 1919, and 50:622–628, 1922 (note correction in 53:448, 1925).

Solar Radiation at Normal Incidence

Ordinarily, measurements of the intensity of solar radiation on a surface normal to the solar rays are made only on working days when the sky is free from clouds; occasionally they are made on dusty or smoky days, to investigate the effects of these conditions, but observations through clouds would serve no purpose.

Standard instruments for measuring solar radiation at normal incidence are equipped with tubes that insure a minimum exposure to sky radiation. The major instruments used by the Weather Bureau are the Marvin pyrheliometer,[31] the Smithsonian Silver Disk pyrheliometer,[32] and the thermopile; less commonly used are the Ångström pyrheliometer [13] and the pyranometer.[27]

The Marvin pyrheliometer (fig. 13), introduced in 1910, is essentially an electrical resistance thermometer; it has for its sensitive element a blackened silver disk, about 4.5 cm in diameter and 0.3 cm thick, supported on needle points, within a metal case which is inclosed in a wooden block to provide insulation. Imbedded within the silver

[29] Herbert H. Kimball and Irving F. Hand. Investigations of the Dust Content of the Atmosphere, Mo. Wea. Rev., 52: 133–139, 1924.

[30] Irving F. Hand, A Study of the Smoke Cloud over Washington, D. C., on January 16, 1926, Mo. Wea. Rev., 54: 19–20, 1926. On effects of smoke and clouds, see also Mo. Wea. Rev., 52: 478–479; 53: 147–148; 59: 76–77.

[13] Knut Ångström. The Absolute Determination of the Radiation of Heat with the Electric Compensation Pyrheliometer, and Examples of the Application of this Instrument. *Astrophys. Jour.*, 9: 332–346, 1899.

[27] *Smith. Misc. Coll.*, Vol. 66, Nos. 7, 11; Vol. 69, No. 9; *cf.* Vol. 72, No. 13.

[31] U. S. Weather Bureau, Circular Q, pp. 4–15. C. F. Marvin, Upon the construction of the Wheatstone Bridge for electrical resistance thermometer, *Jour. Frank. Inst.*, May 1911. Paul D. Foote, Some Characteristics of the Marvin Pyrheliometer, *Bur. Standards Sci. Paper No. 323*, 1913; Mo. Wea. Rev., 46: 499–500, 1918.

[32] C. G. Abbot, The Silver Disk Pyrheliometer, *Smiths. Misc. Coll.*, Vol. 56, No. 19, 1911; see also *Smiths. Misc. Coll.*, Vol. 60, No. 18, 1913, and Vol. 92, No. 13, 1934. *Cf. Annals Astrophys. Obs. Smith. Inst.*, Vol. III, pp. 47–52; *Jour. Opt. Soc. Amer.*, 10: 362–363.

block is a noninductively wound electrical resistance thermometer of insulated nickel wire in the form of a disk, of about 25 ohms resistance. During calibration, the change in resistance of this thermometer with change of temperature is carefully noted; in practice a current of known strength is passed through the coil of wire, and the change in resistance is measured by means of a specially constructed bridge and high sensitivity galvanometer.

The sensitive element is placed at the lower end of a diaphragmed tube that is equatorially mounted; and after the instrument is adjusted for declination and altitude, a clock movement keeps the receiving surface normal to the solar rays. To prevent the generation of too high a temperature, an automatic shutter opens and closes once each minute in front of the open end of the tube; a series of alternate 50-second heatings and coolings over a period of 10 consecutive minutes constitutes a standard observation. The amplitudes of the heatings and coolings progressively diminish during the series.

This instrument requires auxiliary apparatus consisting of a signal clock equipped with contacts which time the action of the relay that opens and closes the shutter; a special Wheatstone bridge; a high sensitivity galvanometer mounted on a rigid base, or preferably on a pier; and two batteries—one a 2-volt cell of constant e. m. f., and the other of 4 volts to actuate the shutter. Lead storage cells have been found most satisfactory, as their discharge rate immediately following the loss of the supercharge, or "peak," is very uniform.

Marvin pyrheliometers are first carefully calibrated in the laboratory, and then compared at frequent intervals with Smithsonian substandards which in turn are compared with the Smithsonian standard water-flow pyrheliometer.[33]

The Smithsonian pyrheliometer (fig. 14), used as a secondary standard, is one of the simplest, and yet most accurate, commonly used substandards. Requiring no auxiliary apparatus, it is well adapted to field work, although the computations necessary to reduce readings to gram-calories are tedious. A bent-tube mercurial thermometer is mounted within a silver disk, the upper side of which is blackened with a nonselective matt coating; and the whole unit is placed at the lower end of a diaphragmed tube which confines radiation to that received from the sun and from a very small ring of sky about it, and also prevents cross currents of air from blowing across the receiving surface. The disk is alternately exposed to and shielded from the sun, and the rise and fall of temperature noted. The tube is equatorially mounted, but requires manual adjustment.

This instrument is carefully calibrated against a standard waterflow pyrheliometer,[34] the primary standard, before issuance by the Smithsonian Institution, in addition to having its characteristics computed from the known properties of the elements going into its construction.

Recently, thermopiles mounted within diaphragmed tubes in much the same manner as the sensitive elements are mounted in the Marvin and Smithsonian pyrheliometers, and carefully calibrated against Smithsonian standards, have been used for continuous records of normal incidence intensity by the Blue Hill Observatory and the Weather Bureau.[35]

[33] *Smith. Misc. Coll.*, Vol. 87, No. 15, 1932.

[34] *Ann. Astrophys. Obs. Smiths. Inst.*, II: 39-47; III: 52-72, discuss pyrheliometric standards.

[35] Herbert H. Kimball, Turbidity and Water Vapor Determinations from Solar Radiation Measurements at Blue Hill and Relations to Air Mass Types, Mo., WEA. REV., 62: 330-333, 1934; Solar Observations, Mo. WEA. REV., 60: 26 and 62-63, 1932.

The Ångström pyrheliometer,[13] (fig. 24) is widely used throughout Europe; but since 1914 other instruments have replaced it for Weather Bureau purposes. The sensitive element consists of two blackened thin ribbons of manganin side by side in a nickel-plated tube with a shutter at the outer end which exposes the strips alternately to the sun; copper-constantin thermoelectric couples are attached to the backs of the strips. An electric current is passed through the shaded strip, and the amperage necessary to balance the heating of the exposed ribbon is multiplied by a factor appropriate to the particular instrument to determine the rate of radiation receipt. Because of the rectangular shape of the receiving surface, the results are vitiated somewhat more by sky radiation than in the case of instruments with circular receiving surfaces.

The Weather Bureau thermoelectric pyrheliometer,[19] when equatorially mounted, may likewise be used for normal incidence measurements.

All the measurements of the intensity of direct solar radiation at normal incidence at the stations which take such observations are published month by month in the REVIEW, with their departures from normal.

Table 5 gives the monthly mean values for the periods of record at Washington, Madison, Lincoln, and Blue Hill of (1) I_m, the observed solar radiation intensity at normal incidence, for different air masses[36] during the morning; (2) similar values of I_m during the afternoon; (3) the average of the preceding morning and afternoon values; (4) this average reduced to mean solar distance in accordance with the annual tables of the earth's radius vector in the *American Ephemeris;* (5) the ratio of the reduced mean value to the solar constant, in percent, and (6) atmospheric transmission coefficients computed from the formula

$$a=\left(\frac{I'}{I_0}\right)^{\frac{1}{m}}, \tag{1}$$

where m=air mass, I'=measured normal incidence intensity, and I_0=the mean solar constant corrected to the mean value of the radius vector for the month (if measured intensities corrected to mean solar distance, and the mean value of the solar constant $I_0=1.94$ be used, instead, the results are the same).

The data for Washington, Madison, and Lincoln are based on observations taken over a period of more than 20 years at each station, while those for Blue Hill include all observations taken there since the work was begun in 1933.

Figure 15, a graph of equation (1), has been prepared to simplify the computation of atmospheric transmission coefficients; after correction of the observed values to mean solar distance, the coefficient may be read off directly.

The above method of obtaining transmission coefficients is strictly valid only for monochromatic radiation; but the coefficients so obtained serve a useful purpose, and commonly are used to compare conditions of the sky at

[36] The air mass (not to be confused with the totally different significance of this term in synoptic meteorology) is the length of the path through a homogeneous atmosphere over which the same attenuation would be produced as takes place in the actual path of the solar beam. It is approximately equal to sec z, where z is the zenith distance of the sun; to take account of refraction, curvature of the earth, etc., Bemporad's formula

$$m=\frac{\text{atm. refr. in seconds}}{58.36\times \sin z}$$

is the most widely used, and has been employed in table 6. Other formulae have been constructed by Forbes, Bouguer, and Laplace. At some stations, and particularly at isolated points where only a few measurements are made, the height of the sun is measured directly by means of a theodolite, and near noon the secant of the sun's zenith distance used as the air mass. See *Smiths. Mell. Tables*, 5 ed., pp. lxxix and 226, 1931.

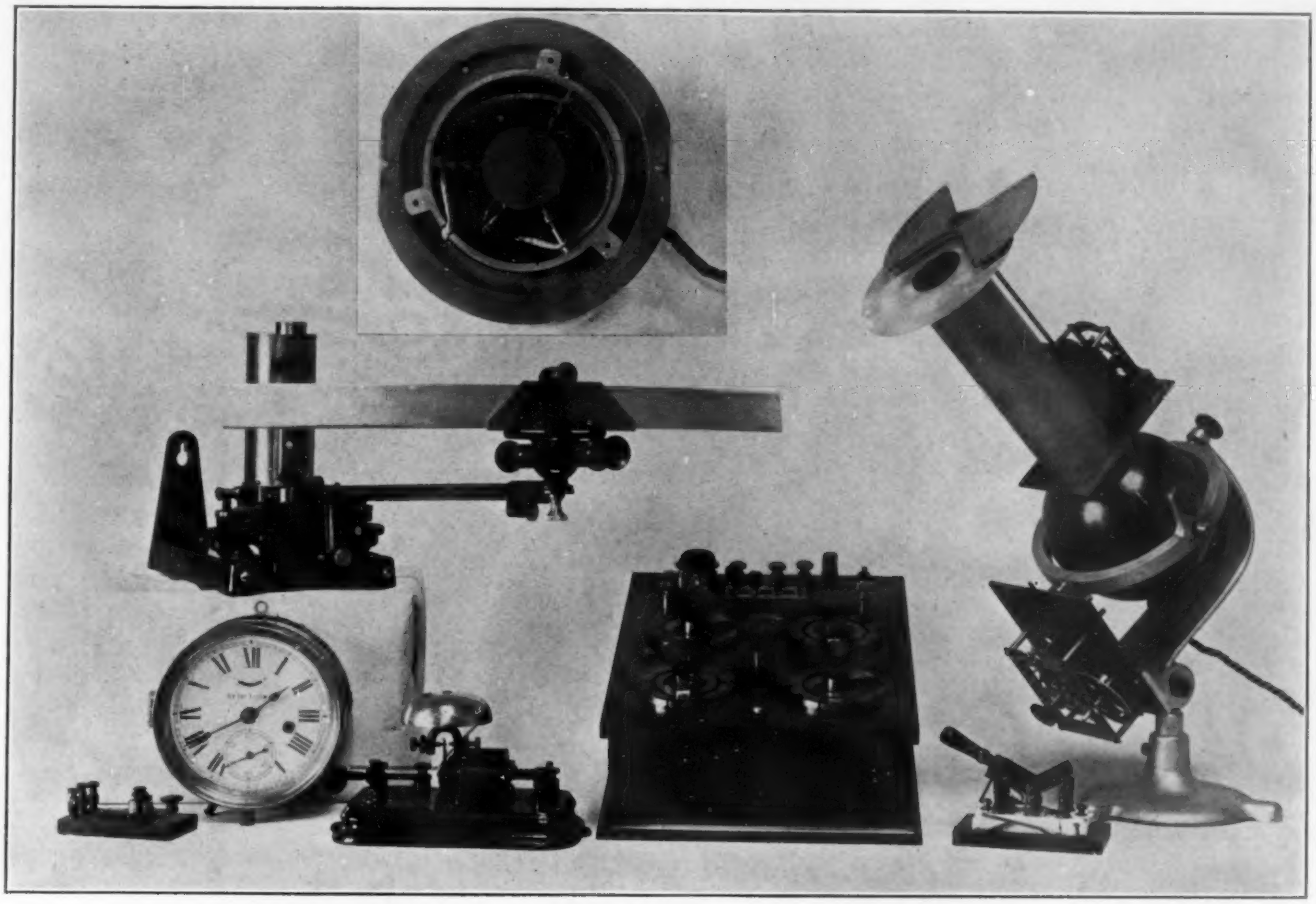


FIGURE 13.—Marvin pyrheliometer and accessories and cross section of bulb.

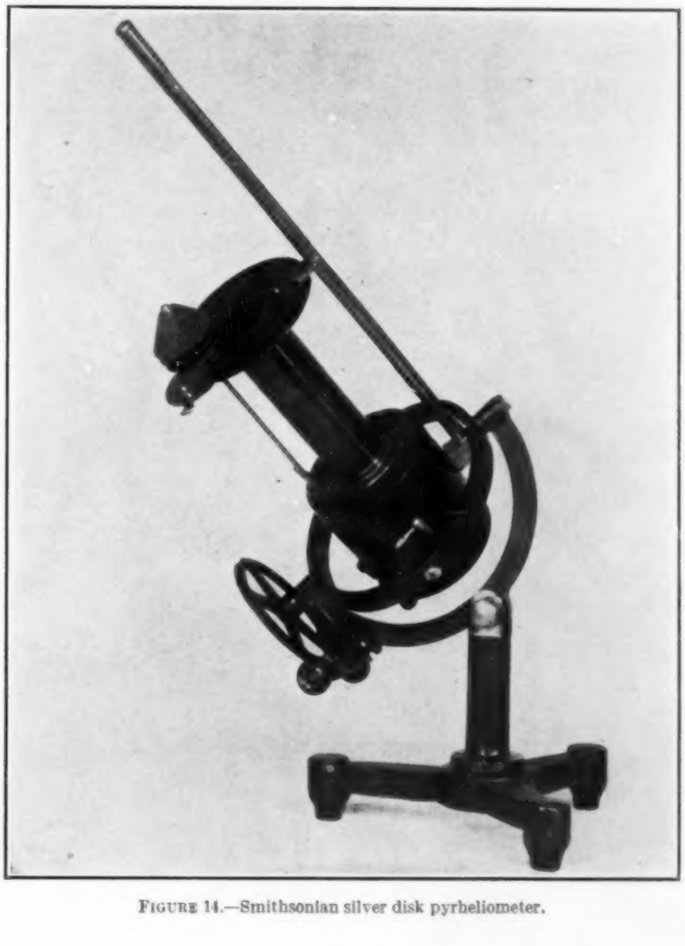


FIGURE 14.—Smithsonian silver disk pyrheliometer.

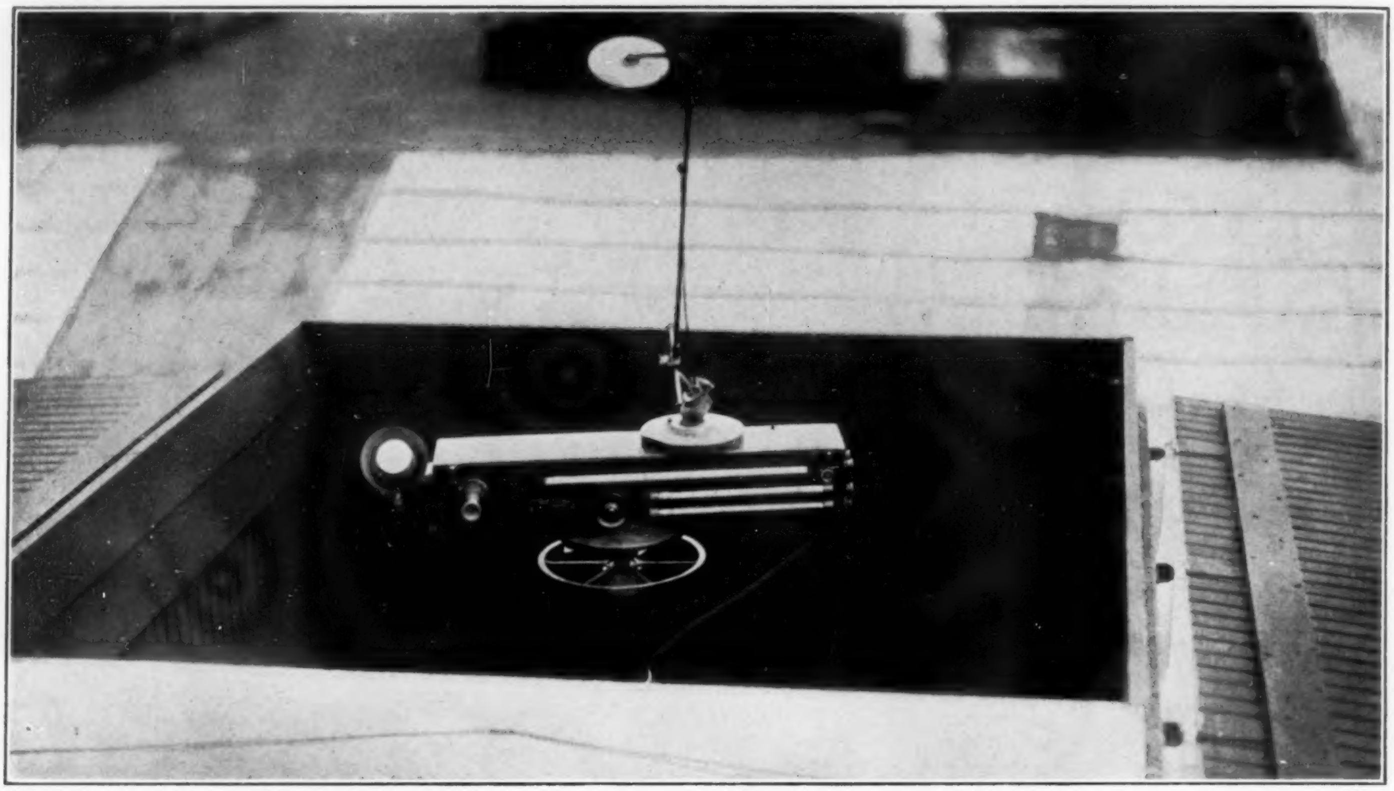


FIGURE 22.—Sharp-Millar photometer.

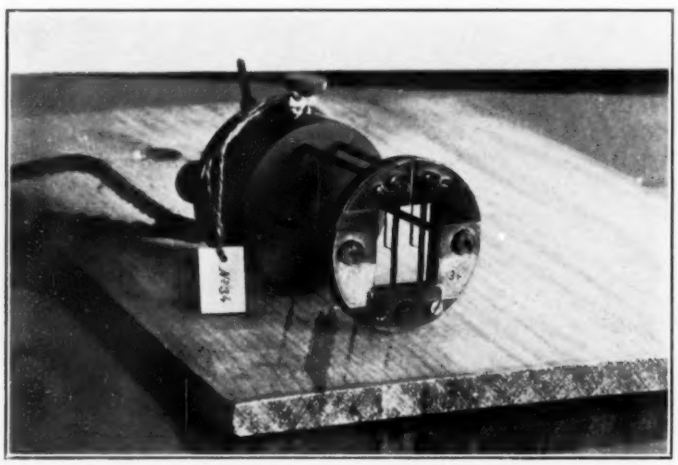


FIGURE 24.—Ångström electrical compensation pyrheliometer.

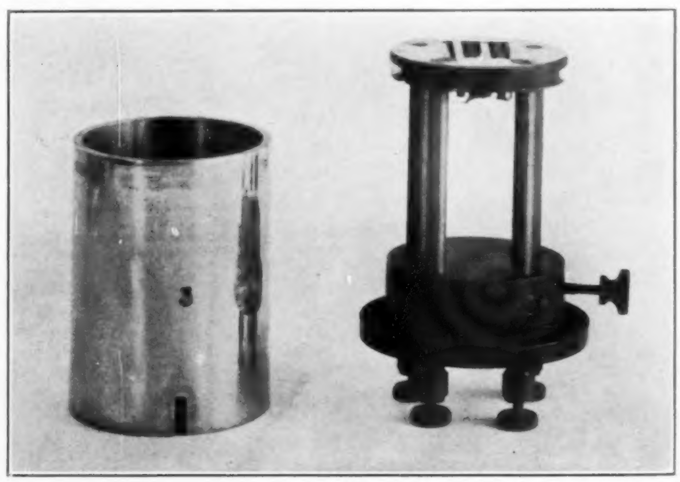


FIGURE 25.—Pyrgeometer.

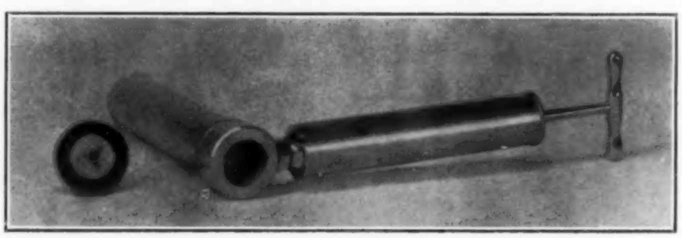


FIGURE 26.—Owens dust counter.

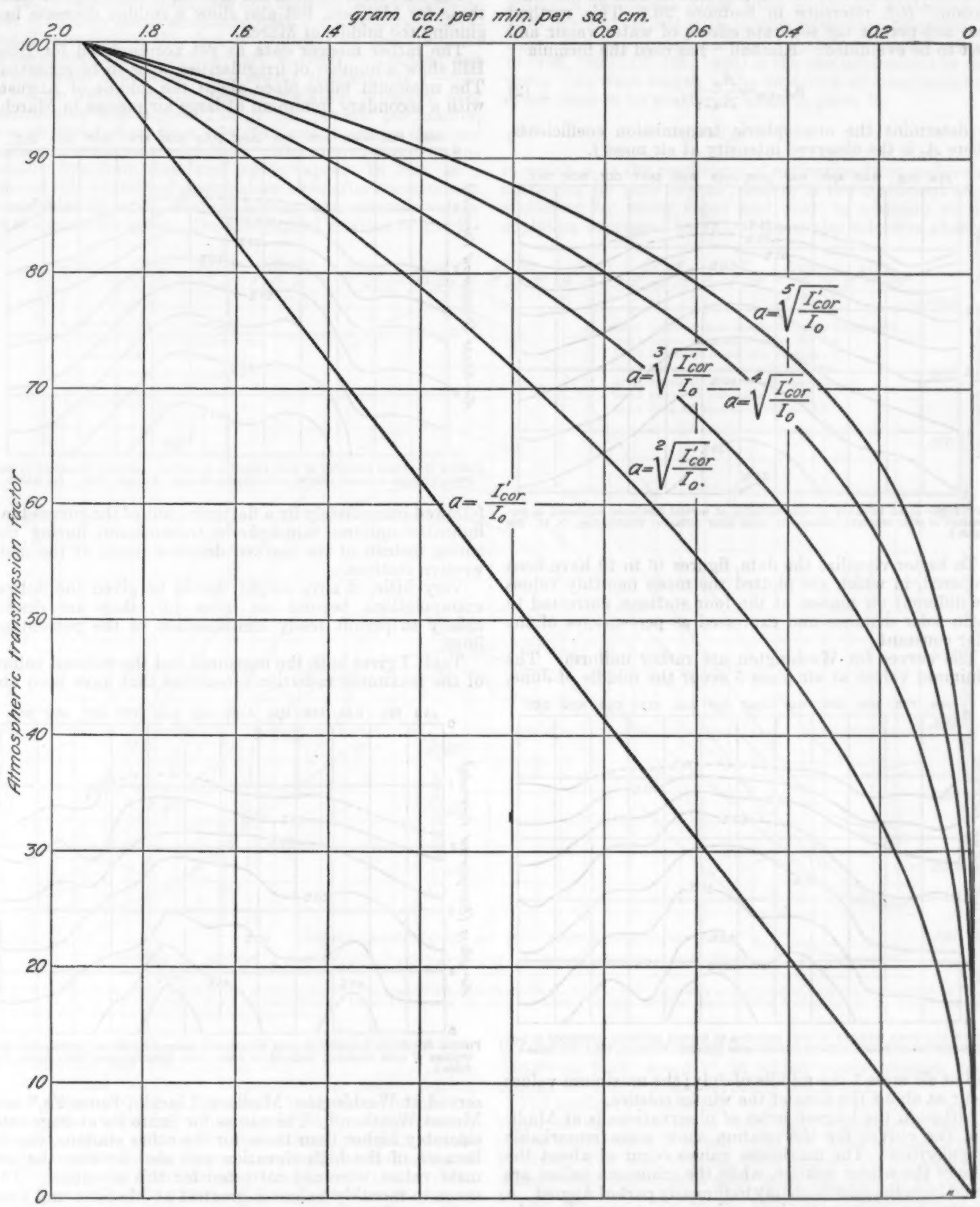


FIGURE 15.—Chart for calculation of atmospheric transmission coefficients by equation (1). Abscissae are intensities at normal incidence, corrected to mean solar distance.

different stations and during different months at the same station. (*Cf.* reference in footnote 26.) This method does not permit the separate effects of water vapor and dust to be evaluated. Kimball [37] has used the formula

$$a_{m-1,m}=\frac{A_m}{A_{m-1}} \tag{2}$$

to determine the atmospheric transmission coefficients, where A_j is the observed intensity at air mass j.

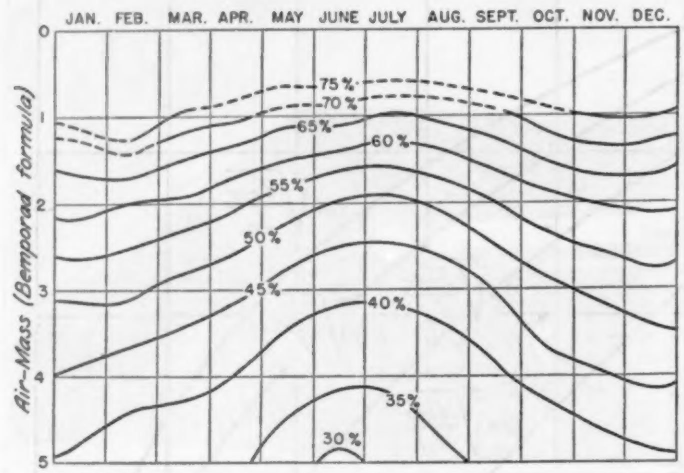


FIGURE 16.—Mean intensity of solar radiation at normal incidence, expressed as percentage of solar constant, reduced to mean solar distance: Washington, D. C. See table 5.

To better visualize the data, figures 16 to 19 have been prepared, in which are plotted the mean monthly values for different air masses at the four stations, corrected to mean solar distance and expressed as percentages of the solar constant.

The curves for Washington are rather uniform. The minimum values at air mass 5 occur the middle of June,

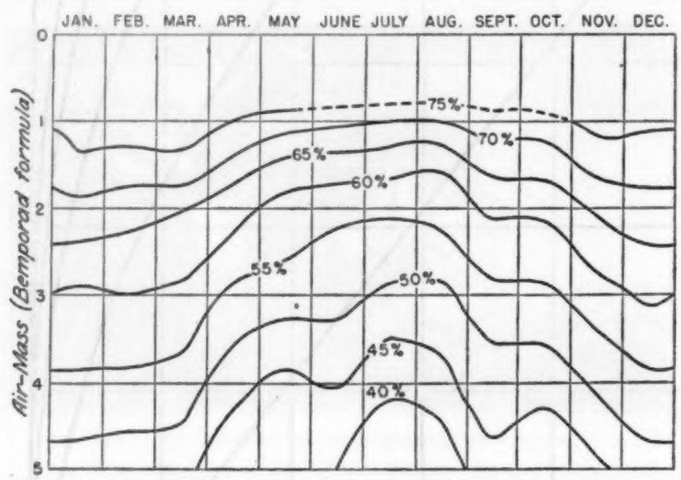


FIGURE 17.—Mean intensity of solar radiation at normal incidence, expressed as percentage of solar constant, reduced to mean solar distance: Madison, Wis. See table 5.

and at air mass 1 the middle of July; the maximum values occur at about the time of the winter solstice.

Although the longest series of observations is at Madison, the curves for this station show some remarkable irregularities. The maximum values occur at about the time of the winter solstice, while the minimum values are found from the middle of July to the early part of August. A summer maximum at the larger air masses occurs about the middle of June. The most remarkable feature, however, is the sudden decrease that begins the middle of March.

The curves for Lincoln are somewhat more regular than those for Madison, but also show a sudden decrease beginning the middle of March.

The rather meager data as yet accumulated for Blue Hill show a number of irregularities, as is to be expected. The minimum takes place about the middle of August, with a secondary minimum at large air masses in March,

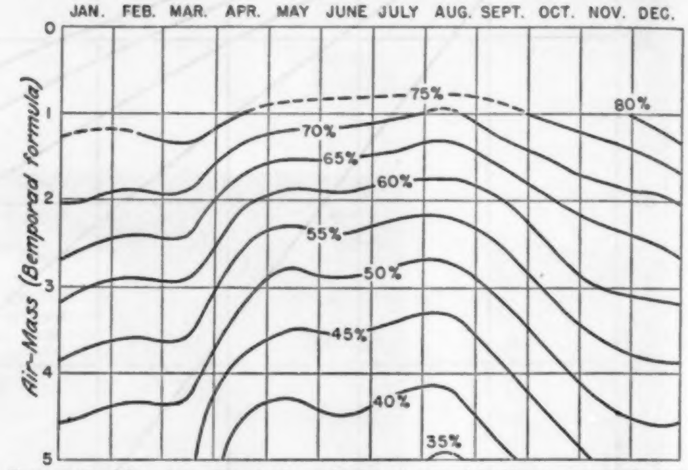


FIGURE 18.—Mean intensity of solar radiation at normal incidence, expressed as percentage of solar constant, reduced to mean solar distance: Lincoln, Nebr. See table 5.

followed immediately by a flattening out of the curves that indicates uniform atmospheric transmission during the spring instead of the marked decrease found at the midwestern stations.

Very little, if any, weight should be given the dotted extrapolations beyond air mass 1.0; they are drawn chiefly to permit ready identification of the percentage lines.

Table 7 gives both the measured and the reduced values of the maximum radiation intensities that have been ob-

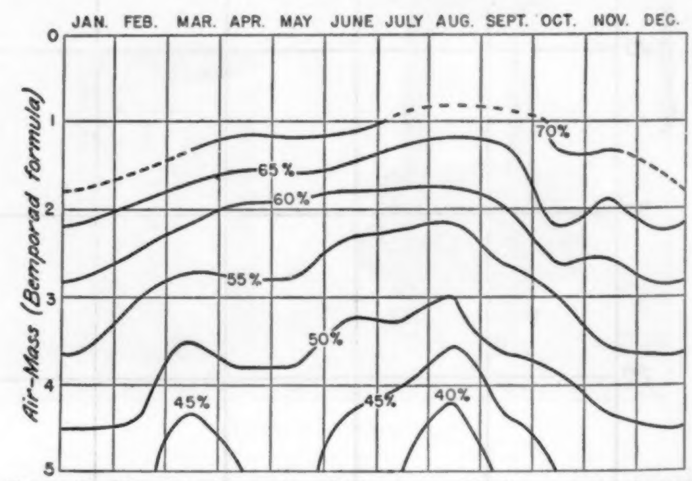


FIGURE 19.—Mean intensity of solar radiation at normal incidence, expressed as percentage of solar constant, reduced to mean solar distance: Blue Hill, Mass. See table 5.

served at Washington, Madison, Lincoln, Sante Fe,[38] and Mount Weather.[39] The values for Sante Fe average considerably higher than those for the other stations, chiefly because of the high elevation and also because the air-mass values were not corrected for this elevation. The range in monthly values is greatest at Madison and least at Mount Weather.

[37] MO. WEA. REV., 58: 45, and 55: 159.

[38] Herbert H. Kimball. Solar Radiation Intensities at Sante Fe. MO. WEA. REV., 43: 590-591, 1915.

[39] Herbert H. Kimball. Solar Radiation Intensities at Mt. Weather, Va. MO. WEA. REV., 42: 520, 1914.

Large radiation intensities and high air temperatures do not ordinarily occur simultaneously. An especially striking illustration of this fact is provided by conditions at Washington, D. C., on February 9, 1934:[40] On that day Washington experienced the lowest temperature (−6.5° F.) since 1912; yet the highest radiation intensity ever recorded at Washington, 1.59 gr. cal. per cm² per minute, was observed at air mass 1.74 (64 percent greater than the midsummer air mass of 1.055). The atmosphere was unusually free from dust and water vapor. In fact, as a general rule winter radiation values, even after correction to mean solar distance, average higher than summer values at the same air mass. On the general relation of insolation to temperature, see Mo. WEA. REV., 54: 417–419, 1926, and 55: 168, 1927 (*cf.* fig. 20).

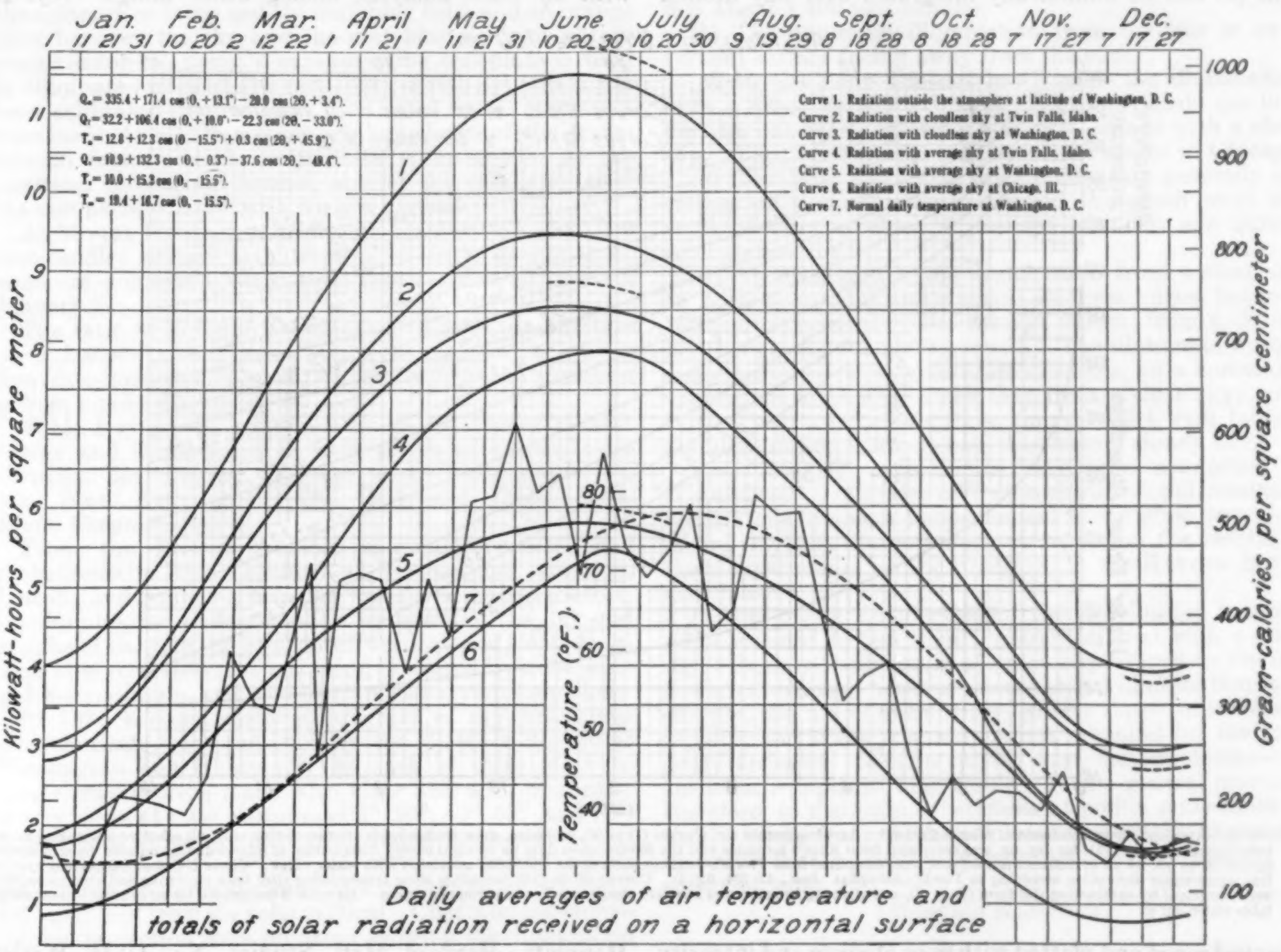


FIGURE 20.—Daily totals of solar radiation on a horizontal surface: The irregular solid line represents the actually observed weekly averages of total solar and sky radiation at Washington, D. C., during 1925; curves 2 to 6 are mean values. Curve 1 represents the insolation outside the atmosphere at the latitude of Washington, D. C. The short dotted segments show values reduced to mean solar distance.

The normal incidence measurements made during recent years with the thermopile[35] have been for the purpose of determining atmospheric water vapor content and turbidity, as part of an international program recommended in 1931 by the Commission on Solar Radiation of the International Geodetic and Geophysical Union (Mo. WEA. REV., 59: 187, 1931). The so-called coefficient of turbidity is an index which expresses the depletion of solar radiation by causes other than molecular scattering in pure dry air; several such indices have been proposed, of which the one introduced by Ångström (*Geograf. Ann.*, 11: 156, 1929; 12: 130, 1930) is the one determined in this work. At wave length λ, the depletion of solar radiation at air mass m by scattering alone is given by

$$I_\lambda = I_{0\lambda} e^{-(a_1+a_2)\,m} \tag{3}$$

in which a_1 is the coefficient of extinction from molecular scattering by pure dry air, and a_2 is the coefficient from scattering by water vapor and dust; in addition ot the depletion expressed by (3), there is also selective absorption by water vapor and by the other constituents of the air. Ångström finds $a_2 = \beta/\lambda^n$, in which under average conditions $n = 1.3$; β is the turbidity coefficient.

The method for determining β and the amount of water vapor in the atmosphere from solar radiation measurements is described in detail by H. H. Kimball and Irving F. Hand, The use of glass color screens in the study of atmospheric depletion of solar radiation, Mo. WEA. REV., 61: 80–83, 1933; and H. H. Kimball, Determinations of atmospheric turbidity and water vapor content, Mo. WEA. REV., 64: 1–6, 1936. The thermopile is equipped with glass color screens, mounted on the end of the tube, which do not transmit the sections of the solar spectrum

[35] Herbert H. Kimball, Turbidity and Water Vapor Determinations from Solar Radiation Measurements at Blue Hill and Relations to Air Mass Types, Mo., WEA. REV., 62: 330–333, 1934; Solar Observations, Mo. WEA. REV., 60: 26 and 62–63, 1932.

[40] Irving F. Hand. Solar Observations. Mo. WEA. REV., 62: 62, 1934.

that are free from important atmospheric absorption bands (*cf.* fig. 5); the measured intensity of the radiation transmitted through a color screen is corrected for reflection and absorption by the screen, including the effect of temperature (Mo. Wea. Rev., 64: 4–6; 65: 111, 195), and when the corrected value I' is subtracted from the observed intensity of the total solar radiation at normal incidence I_m, the difference $I=I_m-I'$ represents the intensity of radiation that has been materially depleted only by *scattering* by dry air, water vapor, and dust. The depletion from scattering by dry air can be computed with the formulae developed by Rayleigh and King;[12] hence, for each of a series of assigned values for β, equation (3) can be numerically integrated over any desired spectral range and plotted with m as abscissa and intensity of radiation as ordinate, since the intensity distribution outside the atmosphere is known. From the family of curves for the spectral range of I, the value of β for any observed value of I may be read off. A similar family of curves for I_m may be constructed, from which the value of I_m for any β may be read off; the difference between this value and the observed value of I_m is the depletion by selective atmospheric absorption. The absorption by the permanent gases can be estimated (*Smiths. Misc. Coll.*, Vol. 81, No. 11); and from the remainder, the depth of water w that would be formed if all the water vapor above the point of observation were precipitated may be obtained from charts based on relations established experimentally by Fowle (*Smiths. Misc. Coll.*, Vol. 68, No. 8) and graphically represented in figure 21 (Mo. Wea. Rev., 55: 166–168; 56: 393–394; 58: 50–52; *Smiths. Metl. Tables*, 5 ed., lxxxii–lxxxv, 239–240). The determination of β and w, however, is a problem that needs further investigation; in particular, the results obtained from the methods and curves used in Europe do not seem to be consistent with those obtained from the curves used in the United States. (See Mo. Wea. Rev., 64: 377, 430, 1936; 65: 18, 62, 1937.)

The investigations of atmospheric turbidity and water vapor content are of considerable interest in connection with air mass analysis, among other things. (*Cf.* B. Haurwitz, Harvard Metl. Studies, No. 1; H. Wexler, Mo. Wea. Rev., 62: 397–402, 1934; H. H. Kimball, Mo. Wea. Rev., 62: 330–333, 1934.)

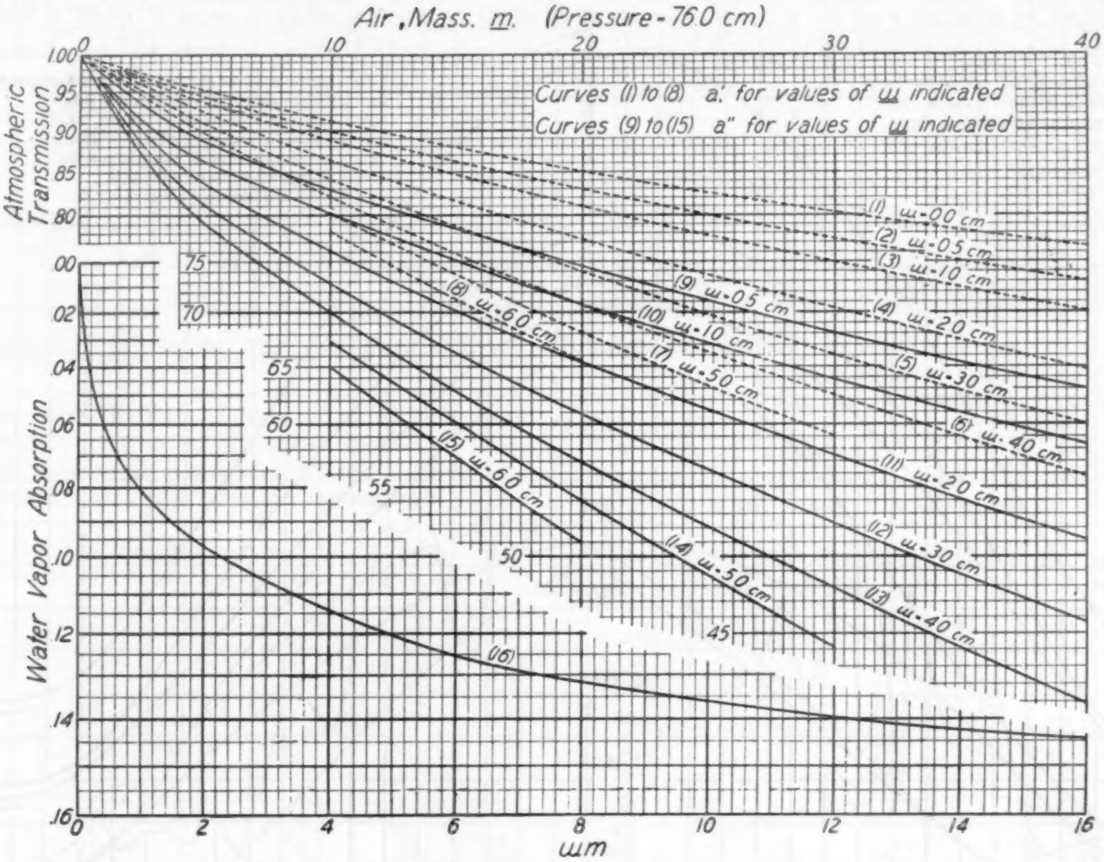


FIGURE 21.—Atmospheric transmission of solar radiation by dust-free humid air: Curves (1) to (8), inclusive, show transmission after scattering only, all selective absorption having been neglected; curve (1), for dry air, was computed from King's formulae and the Smithsonian data on spectral energy distribution of solar radiation outside the atmosphere; curves (2) to (8), for air of different humidities, were computed from Fowle's determination of the scattering associated with water vapor. Curve (16) shows depletion by selective water vapor absorption according to Fowle (*Astrophys. Jour.*, 42: 394, fig. 4). Curves (9) to (15), inclusive, show transmission after both scattering and absorption; they were computed by subtracting (16) from (2) to (8), and allowing for estimated selective absorption by the permanent gases. Air mass is designated by m; centimeters of precipitable water, by w.

The measurements at Washington and Blue Hill of the solar radiation transmitted by the color screens, and the deduced values of β and w, together with the air mass type at the time, are published monthly in the Review.

Daylight Illumination

Figure 2 shows the spectral range of the solar radiant energy that reaches the surface of the earth, together with the extent of the range to which the human eye is sensitive and which is commonly termed *visible* radiation. The figure shows the way in which the position of the maximum intensity shifts from the ultraviolet to the infrared with

[12] See W. J. Humphreys, *Physics of the Air*, 2 ed., pp. 537–546; L. V. King, On the scattering and absorption of light in gaseous media, with applications to the intensity of sky radiation, *Phil. Trans.*, A212: 375–434, 1913. F. E. Fowle, The atmospheric scattering of light, *Smith. Misc. Coll.*, Vol. 69, No. 3, 1918.

increase in air mass; because of this shift, the ratio of total solar and sky radiation to the visible component of this total radiation undergoes large variations.

Measurements of daylight illumination on a horizontal surface freely exposed to both the sun and the total hemisphere of the sky, and also on a horizontal surface exposed to the sky alone, were first made by the Weather Bureau at Mount Weather, Va., in 1913.[41] Readings were taken only with either clear or uniformly clouded skies, because with partly cloudy skies the illumination varies so rapidly that observations are valueless.

A Sharp-Millar photometer with certain modifications [42] (fig. 22) has been adopted by the Weather Bureau for this work: A blue filter is placed in the optical train between the comparison lamp and the matching field, and an orange filter between the sky and the matching field, to obtain proper color relations; a compensating test-plate is used to eliminate errors at low sun. The whole apparatus has been calibrated frequently at the United States Bureau of Standards, to assure a thorough knowledge of the transmission factors, of the corrections to be applied to the electrical measuring devices, and of the candlepower of the comparison lamp with known current.

At Mount Weather, a maximum illumination of 10,000 foot-candles occurs with clear skies in midsummer at noon, as compared with 3,600 foot-candles at noon in January.[43]

The ratio of skylight illumination to total illumination on a horizontal surface at noon in midsummer varies from one-third to one-tenth, while in winter the variation is from one-half to one-fifth.

Table 8 gives the relation between total solar radiant energy and illumination in foot-candles at various solar altitudes for Mount Weather and Washington (*Cf.* Mo. Wea. Rev., 52:473–479, 1925; and *Trans. Inter. Illum. Congress*, 1928).

From the Mount Weather illumination data, and pyrheliometric data obtained at Washington, Madison, Lincoln, and Sante Fe, Kimball[44] prepared charts showing the illumination in foot-candles by hours of the day and months of the year, on horizontal, vertical, and sloping surfaces at several different latitudes, produced by total solar and sky radiation, and also by direct solar radiation alone.

In 1921 a comprehensive program of sky brightness measurements was conducted by the Weather Bureau at Washington and Chicago.[45] At each of these stations, measurements were made with clear and with uniformly cloudy skies, at solar altitudes of 0°, 20°, 40°, 60°, and 70°. A complete series of readings included measurements of sky brightness at 2°, 15°, 30°, 45°, 60°, 75°, and 90° above the horizon on vertical circles at azimuths of 0°, 45°, 90°, 135°, and 180° from the solar vertical. Charts on the stereographic projection were prepared showing the distribution of sky brightness, and giving values in milli-lamberts for each 10° segment of the sky, for different solar altitudes and for clear, cloudy, and thinly clouded skies.

The results of this investigation may be briefly summarized as follows:

[41] Herbert H. Kimball. Photometric Measurements of Daylight Illumination on a Horizontal Surface at Mount Weather, Va. Mo. Wea. Rev., 42: 650–653, 1914.

[42] Clayton H. Sharp, and Preston S. Millar, A New Universal Photometer, *Electrician*, 60: 562–565, 1908. *Jour. Opt. Soc. Amer.*, 10: 369–371.

[43] After correction for the difference in altitude between Mount Weather and Davos Platz, Switzerland, the maximum intensity is in good accord with values obtained by Switzer and Dorno. See C. Dorno, Physik der Sonnen und Himmelstrahlung, *Die Wissenschaft*, 63: 46.

[44] Herbert H. Kimball, Variations in the total and luminous solar radiation with geographical position in the United States, Mo. Wea. Rev., 47: 785, 1919.

[45] Herbert H. Kimball and Irving F. Hand, Sky brightness and Daylight Illumination Measurements, Mo. Wea. Rev., 49: 481–488, 1921; Daylight Illumination on Horizontal, Vertical, and Sloping Surfaces, Mo. Wea. Rev., 50: 615–628, 1922 (*Cf. Trans. Illum. Eng. Soc.*, 16: 255–283; 18: 434–474; Mo. Wea. Rev., 53: 448).

(1) A maximum illumination of 11,000 foot-candles occurs at Washington at noon in midsummer, as compared with about 10,000 on Mount Weather at the same period.

(2) With a cloudy sky, the illumination on a horizontal surface is nearly twice that on a vertical surface, because the region of maximum sky brightness is in or near the zenith.

(3) With high sun, as at midday in summer, the illumination from a cloudy sky averages higher than the illumination from a clear sky, except on vertical surfaces facing the sun.

(4) The maximum illumination from a clear sky occurs on vertical surfaces facing the sun, from early June to early September between 8:30 a. m. and 3:30 p. m., when it is about 1,400 foot-candles.

(5) The minimum illumination from skylight is on a vertical surface facing away from the sun.

(6) In the Loop District in Chicago the illumination from a cloudless sky averages about two-thirds the illumination at Washington on a similar surface with a clear sky. This, of course, is because of the smoke in Chicago.

(7) The total solar and sky illumination generally increases on surfaces sloping toward the south until the angle of slope reaches 20°, except with low sun during summer months.

(8) At Washington, the illumination from a clear sky on both horizontal and vertical surfaces varies between 150 and 60 percent of the average values; from a cloudy sky, between 200 and 30 percent. The illumination from a sky partly covered with white clouds is, on a horizontal surface, three to four times that from a clear sky; on a vertical surface, two to three times. With rain falling, the illumination is about half that from a cloudy sky.

Very recently, experiments have been conducted at Washington, D. C., with a Weston photronic cell, mounted horizontally under a hemispherical Uviol glass cover, to record daylight illumination. A report on the results of these experiments will be published in the Review in the near future.

During severe thunderstorms, the illumination is sometimes reduced to less than 1 percent of that with a clear sky. Such a condition is of great importance to electric power companies, because when natural illumination falls sharply, the use of current for lighting purposes increases rapidly; and if the company is not prepared for the suddenly increased demand on its lines, serious damage to electrical equipment may result. It is a general practice, therefore, to maintain substations at points some miles in the directions from which thunderstorms usually approach, in order that additional generators may be started in sufficient time.

Ultraviolet Radiation

The Weather Bureau has not as yet engaged to any great extent in the measurement of the ultra-violet component of solar radiation. From December 1926 to March 1927 the simple chemical method of Webster[46] was tried, in which the amount of bleaching of a methylene-blue-acetone-water solution, exposed to sunlight in quartz tubes, supposedly gives an approximate measure of ultra-violet intensity; but the trial of the method indicated that the results depend upon so many factors, such as the purity of the chemicals and their temperature (which latter is partly dependent upon wind), as to be only very rough.

[46] Herbert H. Kimball, and Irving F. Hand. *Bull. Nat. Res. Counc.*, No. 61, p. 123–125, Washington, 1927.

Measurements of ultra-violet solar radiation are now being initiated with an apparatus, designed by Coblentz and Stair [47] and consisting of titanium photoelectric cells with a balanced amplifier of the Wheatstone bridge type, recording on a microammeter; the measurements are in absolute units.

SKY POLARIZATION AND BLUENESS

The Pickering polarimeter is used at both Washington and Madison for skylight polarization measurements. The instrument consists essentially of a grid, formed of lead bars spaced at intervals equal to their width. The grid is mounted on the end of a metal tube, and at a proper distance from it is placed a double-image prism that separates the images to exactly the width of the

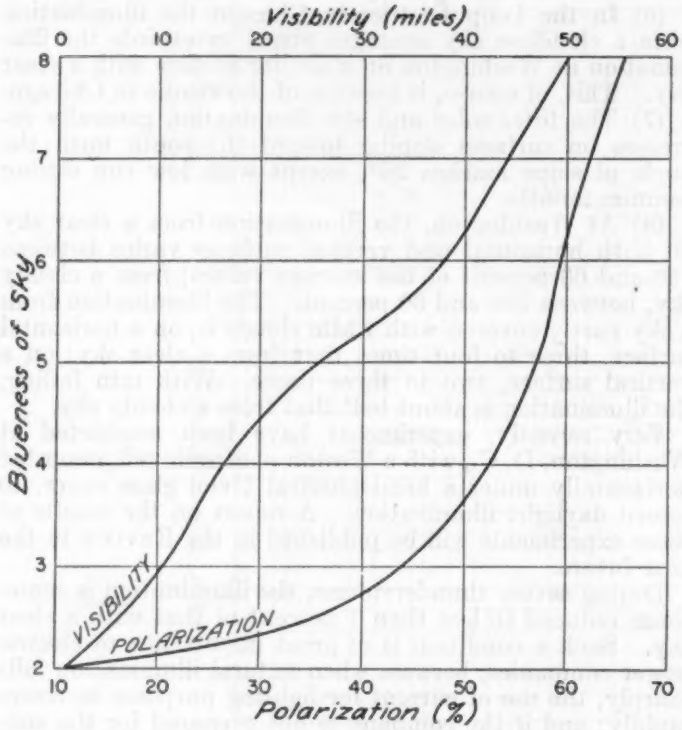


FIGURE 23.—Relations of visibility and sky polarization to sky blueness. See table 11.

bars. When properly focused, and an interposed nicol turned so that the two images are equally bright, the field appears uniform; the slightest turn of the nicol restores the alternate light and dark bands. Observations consist of reading a graduated dial when the field becomes of uniform intensity; the cosine of the angle of rotation gives the percentage of polarization. The instrument is mounted on an upright post, and is equipped with adjustments in both altitude and declination; it is properly adjusted when a small spot of light falls on a cross on a metal disk. Observations are taken at air mass 2.0 on a point in the solar vertical 90° from the sun (ordinarily the point of maximum polarization).

A nicol prism is the best nucleus known for instruments intended to measure sky polarization. A recent attempt to fabricate a recording polarimeter by the use of a well-known organic substitute for nicols was abandoned when it was discovered that this material functioned properly only at visible wave-lengths.

[47] W. W. Coblentz, Methods of Evaluating Ultraviolet Solar Radiation in Absolute Units, Mo. WEA. REV., 64: 319–321, 1936.

Single nicols are useful in locating and studying clouds that otherwise are invisible.[48]

The polariscope is used to observe the location of the neutral points. This instrument consists essentially of a triangular sheet of heavy aluminum, with a swinging arm that may be clamped when a neutral point is found, to permit the determination of the angular height of the point; on one edge of the plate is an optical train, through which polarized skylight gives a field of vertical colored straight lines that disappear when the instrument is pointed toward a neutral point.

Tables 9 and 10 give the results of polarization measurements at Washington, D. C., and Madison, Wis. The original observations in detail are in the Weather Bureau files. Comparisons of polarization measurements with normal incidence intensities at air mass 2 (sun 30° above the horizon) show an increase in polarization with increase of normal intensity, provided the atmosphere is free from dust and cloud, and the ground has no snow or ice cover; reflection from these causes affects the polarization measurements to the point where they finally become valueless.

Many relations have been found between polarization of skylight and other meteorological quantities, especially visibility, relative humidity, vapor pressure,[49] and blueness of the sky.

Table 11 gives the means of all the polarization and sky blueness measurements at Washington, arranged in order of darkening shades of blue. Sky blueness observations consist simply of matching the color of the sky, at the point where polarization readings are made, against a standard series of blue cards of varying shades. Similar observations are made at the Blue Hill Observatory of Harvard University; both sets of color cards were furnished by F. Linke of the Universitäts-Instituts für Meteorologie und Geophysik, Frankfurt-am-Main, Germany. Sky blueness measurements have also been made by Thomson [50] at Apia, Samoa.

The visibility determinations were made in the usual way, by selecting from a large number of points at known distances the farthest one that could be seen with the unaided eye. It is well known that this type of observation is one of the most difficult to standardize. Figure 23 gives the same data as table 11, with blueness as ordinate, and polarization and visibility as abscissae. There is a very smooth relation between blueness and polarization; but, as might be expected, visibility distances do not plot so well.

SURFACE REFLECTION AND EARTH RADIATION

Of the radiant energy incident on the earth's atmosphere, a portion is reflected and scattered directly back to interplanetary space during passage through the atmosphere; a small part of the remainder is absorbed in the atmosphere, while the rest reaches the surface of the earth either in the direct solar beam or as diffuse scattered light from the sky. Part of the radiation incident on the surface is reflected, and the remainder absorbed; a portion of the reflected radiation escapes directly to space. By the reflection of radiation in the atmosphere and at the surface, and by reradiation of energy absorbed in the atmosphere and on the surface, the earth is continually sending out radiant energy to space, and in the long run emits the same amount that is received from the

[48] Irving F. Hand. An aid in locating and studying clouds. Mo. WEA. REV., 61: 302–303, 1933.
[49] Irving F. Hand. Blue-Sky Measurements. Mo. WEA. REV., 55: 235–236, 1927.
[50] Andrew Thomson. Blue-Sky Measurements at Apia, Samoa. Mo. WEA. REV. 56: 499, 1928.

sun. (See C. G. Abbot, Radiation of the planet Earth to space, *Smith. Misc. Coll.*, Vol. 82, No. 3.) Measurements of surface reflection, and of radiation from the surface and from the atmosphere, are coordinate in importance with observations of incident solar radiation; the ceaseless flows and transformations of energy are fundamental in the dynamical mechanism of the atmospheric and oceanic circulations. (See, e. g., Mo. WEA. REV., 59: 476–479, 1931; 57: 491–498, 1929.)

Reflectivity of Natural Surfaces

In 1929 a Munro photometer, especially designed for measuring the reflection from ground and water surfaces from airplanes, was received from L. F. Richardson of London; and with it, the Weather Bureau took part in an international program of observations sponsored by the International Union of Geodesy and Geophysics.[51] The instrument has an optical train about 1 meter in length; on one end of the cylindrical metal casing is a brass head with two windows, one of fixed diameter facing the sky, and the other containing an iris diaphragm facing the ground. A soft-rubber eyepiece prevents possible injury when observing in a turbulent atmosphere.

Readings are made only under uniformly clouded skies, when the relation of the brightness of the zenithal point to that of the entire sky is well known.[45] The photometer was mounted on the side of an open cock-pit of an army observation plane, and flights were made over many kinds of surfaces including differently colored ploughed fields, forests of evergreen and of deciduous trees in varying states of foliage and color, level and hilly sections, freshly fallen and older snow surfaces, cities, rivers, and the ocean.

The observations [52] show a marked weakness of the green component in light reflected from a light-colored ploughed field. Most remarkable is the strength of the red component in light from grassy fields and forests; one reason why the green is so predominant to the eye, but becomes secondary in photometric measurements, is the fact that both the greatest sensitivity of the eye and the maximum point on the solar spectral energy curve lie in the green. It is also known that chlorophyll is fluorescent, reflecting back a considerable red component; while leaves, both during the growing season and immediately after the decomposition of the chlorophyll in the autumn, contain two coloring agents, xanthophyll and carotin, that introduce a strong red component.

The albedo of snow surfaces is too large to be measured with the above type of photometer. (See Mo. WEA. REV., 58: 59–60, 1930, for observations with another instrument.) Among other surfaces observed, seashore sand and light-hued ploughed fields reflected the greatest percentages of total light; forested areas on steep slopes, the least. Clean rivers reflected the most green, and forest areas the least. Grassy fields, muddy rivers, and ordinary forest areas showed the largest amounts of red, while dark-hued ploughed fields and cities reflected the least. Readings with a blue filter were difficult to make because it took so long for the eye to become accustomed to this nearly monochromatic short-wave radiation; the few measurements obtained with this filter were highest over light colored ploughed fields, and least over dark-hued ploughed fields and forest areas (*Cf.* Ångström, *Geograf. Ann.*, 7:323, 1925).

[51] L. F. Richardson. Union Géodésique et géophysique Internationale, Section de Météorologie. Troisième Assemblée Générale: Prague, 1927. Cambridge, 1928.

[52] Herbert H. Kimball and Irving F. Hand. Reflectivity of Different Kinds of Surfaces. Mo. WEA. REV., 58: 280–282, 1930.

Other instruments are also available for reflectivity measurements. (See e. g., Mo. WEA. REV., 59: 118, 1931.)

Terrestrial Radiation

In 1918 four pyrgeometers were constructed for measuring net out-going radiation from a blackened surface; the thermoelectric junctions were made by W. W. Coblentz of the United States Bureau of Standards,[53] and the mountings were fabricated in the Weather Bureau machine shop.

The pyrgeometer, figure 25, is a modification of the Ångström electrical compensation pyrheliometer;[54] it has two blackened manganin strips and two gold-plated strips, and the procedure in using it is to determine the current necessary to maintain temperature equilibrium between the bright and the black strips when they are exposed to the night sky. Thermocouple junctions are attached to the under sides of the strips. The calibration was made by the Weather Bureau, by means of the Stefan-Boltzmann law

$$R=\sigma(T_1^4-T_2^4)$$

in the form

$$T=Ki^2=\sigma(T_1-T_2),$$

where R is the rate at which heat is exchanged by radiation, K is a constant depending upon the dimensions and electrical properties of the black and gold-plated strips, i is the amperage of the heating current, σ is the radiation constant for a black body (taken to be 8.18×10^{-11} gram calories per minute per square centimeter, or 6½ percent higher than the value used by both K. and A. Ångström), T_1 the temperature of the pyrgeometer, and T_2 the temperature to which it is radiating.

The results [55] of nocturnal radiation measurements at Mount Weather, Va., Washington, D. C., Ellijay, N. C., and Highlands, N. C., are in close accord with those obtained by Ångström [56] after allowance for the difference in the values of σ employed. They show that the temperature of the surface air is very closely related to the temperature of the ground, which in turn depends jointly upon the amount of energy absorbed from the radiation received from sun and sky by day and from the sky by night and the rate at which it is continually lost by radiation. At Washington during January the mean daily surface temperature changes but little from day to day, from which it may be inferred that the radiation absorbed must equal the losses from all sources. At this season of the year the net loss of energy by nocturnal radiation per square centimeter averages about 0.16 gram calories per minute. With increasing declination of the sun there is a progressive increase in the temperature of the ground surface, with resultant increase in net nocturnal radiation until an average maximum of about 0.2 gram calorie per minute is reached in July, with individual maximum values of about 0.3. At extremely low free-air temperatures, the rate of radiation from the earth decreases markedly; the net loss is also greatly decreased at night by clouds, or even changed to a net gain.[59]

[53] W. W. Coblentz. Instruments and Methods Used in Radiometry. Bull. U. S. Bur. Standards, 9: 7–63, 1913.

[54] Knut Ångström, Über die Andwendung der elektrischen Kompensations-methode zur Bestimming der nachlichten Ausstrahlung, *Nova Acta, Regiae societatis Upsaliensis*, Ser. IV, Vol. 1, No. 2, Upsala, 1908; Mo. WEA. REV., 46: 57–61, 1918; *Smith. Misc. Coll.*, Vol. 65, No. 3.

[55] Herbert H. Kimball, Nocturnal Radiation Measurements, Mo. WEA. REV., 46: 57–70, 1918. *Cf. Rept. Chief of Weather Bureau* 1913–14, p. 14.

[56] Anders Ångström. A study of the radiation of the atmosphere. *Smith. Misc. Coll.* Vol. 65, No. 3, 1915.

[59] See J. C. Ballard. Some outgoing-radiation and surface-temperature measurements at Fargo, N. Dak. *Trans. Amer. Geophys. Union* 1937, Pt. I, pp. 127–130.

Earth radiation is a factor of fundamental importance in many dynamical phenomena of the atmosphere. In particular, it is the process by which great masses of cold air accumulate in the polar regions in winter until an outbreak to lower latitudes eventually occurs in the form of a "cold wave."[57] Terrestrial radiation measurements with an instrument called the melikeron[58] have recently been made by the Weather Bureau at a few northern stations in connection with an investigation of the formation and southward propagation of polar air masses.[59]

Nocturnal radiation measurements have also been made during investigations of protection from frost by heating. It was found[60] that a dense smoke-cloud diminishes nocturnal radiation on an average by about 0.11 gram calories per minute per square centimeter, with maximum effects of nearly 0.30 gram calories; but that the actual heating effect of the more efficient types of oil-burners plays a far more important part in protecting orchards from frost than does the smoke-cloud.[61]

ATMOSPHERIC DUST AND ATMOSPHERIC POLLUTION

At a meeting in Rome, May 1922, 12 countries affiliated with the International Union of Geodesy and Geophysics agreed to participate in an international study of the dust content of the atmosphere; and a representative of each country was allotted an Owens dust counter as the principal instrument for the purpose.

This instrument (fig. 26) consists of three essential parts: (1) The so-called dampening chamber is a nickel-plated brass tube 2½ cm in diameter and 15 cm in length, open at one end and lined with chemically pure white blotting paper which is saturated with distilled water immediately before using. (2) The other end of this tube fits onto a head containing a narrow slot 1 cm long; and above this head is a bed for holding a microscope cover-glass, which latter should not exceed 0.15 mm in thickness. With the cover glass inserted, a cap containing a three-prong spring is screwed down, holding the glass firmly in place. (3) A passageway leads from the space between the slot and the cover glass to a one-way suction pump, by means of which the pressure above the slot may be suddenly reduced and thus cause the saturated air to pass at high velocity through the slot from the dampening chamber and impinge perpendicularly on the cover glass. The sudden reduction in pressure cools the already saturated air below its dew-point, and moisture is condensed on the dust particles. The high speed of the particles causes them to adhere to the cover glass and if the glass is removed immediately, the line of moisture containing the particles will be visible.

After the moisture has evaporated, the cover-glass is mounted and hermetically sealed on a microscope slide, dust side down.

The dust line is located by dark-field illumination under the microscope, after which the particles are counted under 1,000-diameter magnification through a fluorite oil-immersion objective. Slightly higher magnification is used to identify individual particles. The length of the dust line in units of the net-ruled ocular is noted; the particles within a rectangle bounded by the width of the line and the sides of a single square of the rulings are counted, and this number is multiplied by a factor that depends upon the number of strokes taken with the pump when securing the sample. Both the number of particles per cubic centimeter in the atmosphere, and their average diameter are estimated; the mass varies as the cube of the diameter.

Irrespective of the magnification used, the smallest particle that may be seen is about 0.2μ in diameter; the largest is limited chiefly by the width of the slot, but rarely exceeds 10μ.

The Weather Bureau began observations in the latter part of 1922. Measurements were made at Washington, D. C., on each working day at 8 a. m.; and many observations were also taken in other cities, on mountain tops, and during unusual atmospheric conditions at Washington.[62] A number of airplane flights were made to determine the vertical and seasonal distribution of atmospheric dust. The complete original data are in the Weather Bureau files.

Table 12 gives the monthly means, and maximum and minimum values, obtained on the campus of the American University, District of Columbia, from 1922 to 1931. The mean for the entire series is 772 particles per cubic centimeter; the average size of the particles is close to 1.0μ, which agrees well with Ångström's observations.[63]

Ångström has derived formulae to determine approximately the amount of scattering and absorption of solar radiation by dry dust. However, these formulae assume definite average particle sizes. Ångström states that in general the diameters of atmospheric dust particles vary from 1.0μ to 1.5μ; but after violent volcanic eruptions the value may decrease to as low as 0.5μ.[64]

From all the observations at Washington, the following relation between visibility and number of dust particles at that station was derived:

$$C=NhD, \tag{4}$$

where N is the number of dust particles per cubic centimeter, h the relative humidity, and D the visibility in miles. If we omit days with a visibility of 10 miles or less, the value of C is 435,000; with all observations, C=390,000. The wind plays a most important part at this station in determining the number of particles; an easterly component brings city smoke and dust, and the count increases rapidly, while a strong northwest wind brings minimum counts.

Except in dust storms, atmospheric contamination generally is a maximum in cities, and is an important source of depletion of the antirachitic ultraviolet radiation; both dust storms and city atmospheric pollution decrease the ultraviolet in far greater proportion than they do the total solar and sky radiation. During a dust storm on March 18, 1937, at Lincoln, Nebr., with a sky free from clouds, incident radiation was only 0.06 gram calorie per minute per square centimeter at 9 a. m., or about 7 percent of the normal for that time of day and year. In fact, the in-

[57] H. Wexler, Cooling in the Lower Atmosphere and the structure of polar continental air, Mo. WEA. REV., 64: 122–136, 1936; Formation of Polar Anticyclones, Mo. WEA. REV., 65: 229–236, 1937.

[58] L. B. Aldrich. The Melikeron. *Smith. Misc. Coll.*, Vol. 72, No. 13, 1922.

[59] See J. C. Ballard. Some outgoing-radiation and surface-temperature measurements at Fargo, N. Dak. *Trans. Amer. Geophys. Union* 1937, Pt. I, pp. 127–130.

[60] Herbert H. Kimball and Floyd D. Young. Smudging as a protection from frost. Mo. WEA. REV., 48: 461–462, 1920.

[61] See also Herbert H. Kimball and B. G. MacIntire. Efficiency of Smoke Screens as a protection from frost, Mo. WEA. REV., 51: 396–399, 1923, where it is shown by further experimental investigations that frost protection by chemical smokes, such as used for smoke-screens during the World War, is impracticable.

[62] Herbert H. Kimball and Irving F. Hand, Investigations of the Dust Content of the Atmosphere, Mo. WEA. REV., 52: 133–139, 1924; 53: 243–246, 1925; 59: 349–352, 1931. Irving F. Hand, The Character and Magnitude of the Dense Dust Cloud that passed over Washington, D. C., May 11, 1934, Mo. WEA. REV., 62: 156–157, 1934; *cf.* Mo. WEA. REV., 54: 19–20, 1926; 62:15, 1926. Irving F. Hand, Mountain and Valley Atmospheric Dust Measurements, Mo. WEA. REV., 61: 169, 1933. Irving F. Hand, Effect of Local Smoke on Visibility and Solar Radiation, Mo. WEA. REV., 53: 147–148, 1935; *cf.* 57:18, 1929.

[63] Anders Ångström. On Atmospheric Transmission of Sun Radiation II. *Geografiska Annaler*, 1930, H. 2, p. 3, 1930.

[64] It has long been known that violent volcanic eruptions which project large quantities of volcanic dust to great heights appreciably decrease the amount of solar radiation received at the surface of the earth, and at times perceptibly influence the temperature. See: W. J. Humphreys, *Physics of the Air*, 2 ed., New York, 1929; The Greenhouse Effect of Volcanic Dust, Mo. WEA. REV., 65: 261–262, 1937. H. H. Kimball, *Bull. Mt. Weath. Obs.*, 3: 111; 5: 301; 6: 205–220, 1914. H. H. Kimball, Mo. WEA. REV., 41: 153–159, 1913; 46: 355–356, 1918; 52: 527–529, 1924. W. B. Rimmer, *Gerl. Beit. z. Geophys.*, 50: 388–393, 1937.

coming radiation at that time was far less than the normal outgoing radiation for that season.

Many different kinds of dust particles were observed during the investigations. Spores, diatoms, crystals of calcite and gypsum, organic matter of many kinds, volcanic glass, spicules, and mineral particles of many varieties were found. A search was made for cosmic dust; but the difficulty of identifying it and distinguishing it with certainty from products of combustion prevented any positive identifications.

On one occasion, a diatom of unusual appearance was identified by Albert Mann of the Smithsonian Institution as the *Navicula Borealis*, indigenous to Alaska only; the weather maps for the period immediately preceding the collection of this diatom showed that strong northwest winds had prevailed. On another occasion a microscopist of the Bureau of Plant Industry identified a spore obtained in February, long before spores were set free in the latitude of Washington, as being indigenous to Florida only; again the weather maps indicated that strong southerly winds had prevailed for some days. Rust spores obtained at an elevation of 16,000 feet were found to be potent, as they responded to agar cultures.

The season and the conditions of cloudiness have marked effects on the vertical distribution of atmospheric dust. With clear skies, a larger number of dust particles often were found at elevations of one or two thousand feet than near the ground; with cloudy skies, the number of particles diminished rather regularly with height to extremely small values at the top of the dust layer.

During 1926 and 1927, the Weather Bureau also made determinations of the amount of sulphur in the atmosphere.[65] Excessive quantities of sulphur are detrimental to both health and property. In one extreme case, the combination of a large sulphur content with the water vapor which is always present formed sulphuric acid to such an extent that the outer surface of a white marble building was changed into gypsum to a depth of 6 millimeters. Evidences of the ravages of sulphur may be seen in the vicinity of many railroad yards and manufacturing plants; mortar between bricks becomes loosened, metals are corroded and buildings in general take on an exceedingly dingy appearance. Ordinarily two parts of sulphur in a million by volume give a noticeably sulphurous odor to the atmosphere.

[65] Herbert H. Kimball and Irving F. Hand. Measurements of the Sulphur Content of the Atmosphere. MO. WEA. REV., 59: 351-352, 1931.

Sulphur determinations were made by placing equal quantities of a solution of distilled water, iodine, potassium iodide, and soluble starch in two 20-liter bottles, each bottle being tightly sealed but provided with a ground-glass stopcock inserted through a sulphur-free rubber stopper. The pressure within one bottle was reduced to one-half normal. Both bottles were shaken vigorously; the stopcock of the partially evacuated bottle was then opened, the bottle again shaken until normal pressure was restored within, and the liquid then titrated until a color match with the other bottle had been obtained.

All determinations were made on the campus of the American University in the northwest part of Washington, D. C., where the sulphur content of the atmosphere varied considerably, depending upon the wind direction. An easterly wind brought contamination from the city, while a westerly wind usually brought country air. Some contamination resulted from a blast furnace on an adjoining portion of the campus.

An amount of sulphur in excess of one part in a million by volume was observed on only 15 days out of the 600 on which measurements were made. Five of these days were in October, 1928, when the blast furnace was in almost continual operation. In general, a large number of dust particles were observed on days with the larger amounts of sulphur. The average for the entire observing period was close to one part of sulphur in 10 million by volume.

ACKNOWLEDGMENT

The author wishes to express his gratitude for the invaluable assistance of Dr. Edgar W. Woolard in the preparation of this paper.

TABLE 1.—*Pyrheliometric stations*

Location	Direction of	N. lat.	W. long.	Instruments	Pyrheliom. Altitude, m.s.l.	Established
		° ′	° ′		Feet	
Washington, D. C. (American university).	U. S. Weather Bureau	38 56	77 05	Smithsonian, Marvin, Angström comp., Weath. Bur. pyrhel., Eppley-Coblentz pyrhel.	397	October 1914.
				Eppley; Engelhard, and L. & N. rec	414	
				Moll thermopile		
				Ultraviolet and visible radiation		
				Polarimeter, Linke color cards, Owens dust counter, photometer, Richardson airplane photometer, pyrgeometer.		
Madison, Wis. (University of Wisconsin).	do	43 05	89 23	Marvin	974	July 1910.[1]
				Eppley; L. & N. rec	1,009	
				Polarimeter		
Lincoln, Nebr. (University of Nebraska).	do	40 50	96 41	Marvin	1,225	November 1911.[2]
				Eppley; L. & N. rec	1,250	
Chicago, Ill. (University of Chicago)	do	41 47	87 25	Eppley; Engelhard rec	688	September 1923.
New York, N. Y. (Central Park Meteorological Observatory).	do	40 46	73 58	Eppley; Engelhard rec	180	April 1924.
				Black bulb in vacuo		
				Owens automatic filter		
Fresno, Calif	do	36 43	119 49	Eppley, Engelhard rec	330	January 1929.
Pittsburgh, Pa.[3]	do	40 22	79 56	do	1,293	January 1930.[3]
Fairbanks, Alaska	do	64 52	147 39	do	500	August 1931.
San Juan, P. R	do	18 28	66 06	do	85	May 1935.
Gainesville, Fla.[4]	University of Florida	29 39	82 21	Moll; Richárd rec. microammeter	233	January 1930.[4]
Twin Falls, Idaho	U. S. Bureau Entomology and Plant Quarantine.	42 29	114 25	Eppley; Engelhard rec	4,300	January 1927.
La Jolla, Calif	Scripps Institute of Oceanography	32 50	117 15	do	85	January 1930.[5]
Miami, Fla. (Belle Isle Observatory, Coral Gables).	O. J. Sieplein	25 41	80 12	Callendar	50	July 1930.

[1] Record of total solar and sky radiation started April 1911.
[2] Record of total solar and sky radiation started June 1915.
[3] See text. Discontinued in August 1936.
[4] Discontinued December 1933.
[5] See text; record not homogeneous.

TABLE 1.—*Pyrheliometric stations*—Continued

Location	Direction of	N. lat.	W. long.	Instruments	Pyrheliom. Altitude, m.s.l.	Established
		° ′	° ′		*Feet*	
New Orleans, La.	Tulane University	29 56	90 07	Eppley; Richard rec. microammeter	100	March 1931.
Ithaca, N. Y. (Cornell University)	Department Pomology, N. Y. State College Agriculture.	42 27	76 29	Eppley; L. & N. rec.	953	January 1935.
Friday Harbor, Wash.	Oceanographic Laboratory, University of Washington.	48 32	123 01	Eppley; Engelhard rec.	15	July 1932.
Blue Hill, Mass.	Harvard University	42 13	71 07	Smithsonian; Eppley-Coblentz Eppley; Engelhard and L. & N. rec. Linke color cards	640	September 1933.
Mount Washington, N. H.[a]	do.	44 16	71 18	Eppley; Engelhard rec.	6,270	December 1933.[a]
Riverside, Calif.	University of California, College of Agriculture.	33 58	117 28	do.	1,051	June 1933.
Newport, R. I.	Eppley Laboratory	41 30	71 19	Smithsonian; Eppley-Coblentz Eppley; Engelhard and L. & N. rec.	52	June 1937.

[a] Discontinued March 1935. Record intermittent; see text.

TABLE 2.—*Weekly means of daily totals of solar and sky radiation on a horizontal surface, gram calories per square centimeter; stations are in order of increasing latitude*

Station	San Juan	Miami	Gainesville	New Orleans	La Jolla	Riverside	Fresno	Washington	Pittsburgh	New York	Lincoln	Chicago	Blue Hill	Ithaca	Twin Falls	Madison	Mount Washington	Friday Harbor	Fairbanks	Mean, omitting San Juan, Mount Washington, and Fairbanks
Number years data	1	6	3	5	6	3	8	22	2	12	20	13	3	3	10	26	1	3	5	
Midweek date																				
Jan. 4	------	295	222	146	245	234	148	153	89	103	175	81	143	100	165	129	94	68	8	156
Jan. 11	------	300	200	193	254	245	163	152	97	108	185	92	154	96	169	134	115	76	10	164
Jan. 18	------	275	214	202	239	273	189	163	107	113	196	99	182	121	184	156	132	90	15	175
Jan. 25	------	332	237	206	260	280	208	180	110	154	226	120	207	165	189	185	134	98	26	197
Feb. 1	------	351	249	233	253	267	216	204	121	149	224	119	238	208	203	188	172	100	36	208
Feb. 8	------	351	273	262	265	279	248	213	148	161	262	136	250	206	216	207	226	112	49	224
Feb. 15	------	349	310	284	274	297	294	222	170	168	272	141	261	195	260	225	225	119	70	240
Feb. 22	------	374	343	292	314	296	340	261	175	200	298	183	291	208	273	254	226	136	104	279
Mar. 1	------	364	382	286	336	378	382	289	176	242	342	209	306	224	300	280	258	153	144	291
Mar. 8	------	376	402	294	333	413	403	309	200	263	358	210	314	222	338	299	250	201	153	308
Mar. 15	------	421	394	324	348	425	422	326	219	271	377	216	334	248	349	313	231	251	193	327
Mar. 22	------	477	418	346	375	427	455	333	222	286	395	241	350	298	390	318	286	314	172	353
Mar. 29	------	466	487	346	414	441	484	346	241	267	407	240	373	310	378	350	399	388	279	372
Apr. 5	------	471	485	354	423	475	511	371	287	329	413	208	377	265	434	372	465	410	334	392
Apr. 12	------	482	476	364	440	496	577	393	320	316	435	336	370	259	480	400	480	410	380	410
Apr. 19	655	470	523	389	446	501	589	425	344	364	447	334	363	328	464	399	444	445	398	427
Apr. 26	583	478	580	386	453	514	573	450	363	411	450	357	436	373	511	439	436	484	392	454
May 3	485	525	584	381	462	560	626	456	377	389	475	371	486	398	513	438	480	559	401	475
May 10	389	534	598	378	472	552	642	447	380	389	444	383	497	451	590	444	545	572	417	485
May 17	483	490	605	375	438	560	667	471	416	420	523	433	548	579	623	482	563	546	444	511
May 24	533	497	590	408	498	568	676	507	462	446	557	458	574	582	644	492	569	523	442	530
May 31	544	472	543	455	472	560	676	524	478	461	520	461	520	506	580	497	620	529	432	516
June 7	576	526	508	458	434	575	648	495	477	428	550	444	506	490	566	510	582	572	469	512
June 14	627	481	464	439	434	601	701	499	484	435	546	451	512	514	637	507	462	601	502	519
June 21	643	459	440	420	485	614	721	494	490	434	576	464	546	505	698	523	466	600	499	529
June 28	627	515	468	406	503	613	728	531	478	450	603	437	580	520	656	532	448	576	474	537
July 5	638	515	492	400	432	614	704	513	476	454	589	465	555	552	603	529	487	576	446	529
July 12	662	522	459	400	432	603	698	496	488	454	586	459	526	546	601	535	------	610	482	526
July 19	668	513	464	396	453	580	687	484	487	426	583	460	509	526	606	519	------	595	411	518
July 26	668	531	468	381	439	572	664	488	482	425	555	463	505	466	571	509	------	556	434	505
Aug. 2	668	496	424	375	428	567	659	472	454	424	515	377	513	454	541	466	------	546	335	476
Aug. 9	655	516	412	364	397	547	628	441	416	375	496	390	512	443	546	456	------	538	317	467
Aug. 16	623	465	409	345	402	530	619	436	395	363	490	388	509	458	485	441	------	535	298	451
Aug. 23	600	492	386	348	413	514	587	417	379	328	484	390	494	445	528	441	465	502	281	447
Aug. 30	596	474	360	377	392	502	568	418	374	351	443	351	398	371	491	403	424	458	247	421
Sept. 6	588	437	343	383	361	494	570	383	358	314	459	338	360	348	475	374	374	411	187	400
Sept. 13	575	424	344	346	320	462	545	366	332	313	427	294	343	352	454	335	352	360	215	377
Sept. 20	539	433	378	323	328	435	494	366	315	299	421	313	332	342	412	344	315	349	147	367
Sept. 27	542	407	379	339	331	413	465	352	290	278	374	265	333	292	431	292	295	344	123	349
Oct. 4	536	406	357	350	317	387	434	336	257	283	337	262	334	275	385	276	282	226	109	326
Oct. 11	522	368	363	340	285	363	405	307	228	266	306	228	321	289	363	242	253	236	72	307
Sept. 18	501	355	369	318	290	350	371	283	203	214	300	211	296	270	344	217	232	195	63	287
Oct. 25	488	368	339	290	287	342	368	267	180	194	278	179	264	205	297	205	181	164	53	264
Nov. 1	488	345	238	275	269	306	316	246	154	174	238	146	230	146	225	183	119	138	38	227
Nov. 8	500	337	251	262	269	327	307	225	128	148	243	126	196	126	212	164	118	114	30	207
Nov. 15	508	342	220	244	265	301	245	196	121	127	207	102	179	110	166	143	135	103	27	192
Nov. 22	498	328	211	224	263	272	242	189	121	126	206	117	162	102	156	129	116	93	18	184
Nov. 29	477	285	213	209	259	262	221	164	106	109	185	86	149	91	156	124	94	83	14	169
Dec. 6	477	304	215	172	254	213	191	159	87	102	172	69	130	81	111	116	106	80	7	154
Dec. 13	476	308	204	184	252	212	179	136	71	101	166	79	128	82	119	113	118	75	5	146
Dec. 20	433	280	188	190	249	223	149	145	71	97	178	88	142	91	117	120	99	71	6	150
Dec. 27[1]	368	283	249	168	236	220	138	149	84	115	174	85	148	100	133	123	86	68	5	155
Means	------	416	379	319	356	424	391	330	278	281	378	270	351	306	391	324	------	325	216	350

[1] 8-day period.

TABLE 3.—*Mean hourly totals of solar and sky radiation on a horizontal surface, Washington, D. C., 1927–36, inclusive (apparent solar time)*

Gram-calories per square centimeter for hour ending	A. M.								P. M.							
Date	5	6	7	8	9	10	11	Noon	1	2	3	4	5	6	7	8
Jan. 1				1.5	7.7	17.7	22.0	26.3	25.9	23.2	17.1	8.7	1.8			
Jan. 8				1.6	7.7	15.5	21.4	24.8	24.7	21.9	16.6	8.8	1.7			
Jan. 15				2.0	8.5	16.6	22.3	26.2	26.8	23.5	17.7	9.3	3.1			
Jan. 22				2.6	9.5	18.1	24.9	27.8	30.0	27.0	20.4	11.9	3.2			
Jan. 29				3.5	12.4	26.2	31.0	35.8	35.2	28.8	24.8	14.7	4.3			
Feb. 5			0.3	4.2	13.2	23.1	30.0	34.9	35.3	31.4	25.0	14.9	4.8	0.4		
Feb. 12			.5	4.6	13.6	23.4	29.7	33.0	32.7	30.8	24.0	15.2	6.3	.6		
Feb. 19			.8	7.5	19.1	30.2	37.3	41.8	42.0	35.6	28.0	18.3	8.0	.8		
Feb. 26			1.3	9.3	20.5	31.4	38.7	41.7	41.0	38.2	29.8	20.5	9.8	1.2		
Mar. 5			2.0	11.7	22.6	33.2	40.3	45.2	45.7	40.1	31.8	22.8	11.8	2.1		
Mar. 12			2.5	12.0	23.6	34.4	42.2	43.7	42.2	38.2	33.4	23.8	13.0	3.0		
Mar. 19		0.1	2.9	12.4	21.2	30.1	38.0	39.9	40.5	37.4	30.2	21.7	12.6	3.8	0.1	
Mar. 26		.2	4.2	14.8	25.2	34.0	39.4	43.9	42.2	41.4	34.1	25.1	15.7	5.9	.3	
Apr. 2		.4	5.6	16.2	25.5	35.3	41.3	44.5	46.2	43.1	35.6	27.6	16.7	6.2	.5	
Apr. 9		.8	7.3	18.1	29.2	38.5	46.2	50.1	50.2	45.1	37.4	27.1	16.1	6.6	.7	
Apr. 16		1.3	9.2	20.4	32.3	44.0	52.9	52.8	53.1	48.1	42.5	31.0	21.1	9.3	1.4	
Apr. 23		1.8	11.1	24.6	37.8	46.9	54.8	60.2	58.8	52.8	46.8	38.3	26.0	12.2	2.3	
Apr. 30		2.7	11.2	23.0	35.1	46.4	54.6	57.3	57.5	54.0	46.2	34.5	23.7	12.4	2.9	
May 7		2.8	10.4	21.7	31.6	40.0	48.1	53.7	54.0	51.4	44.2	33.1	23.7	12.1	2.8	
May 14	0.1	3.6	12.1	25.3	37.6	46.7	52.4	56.4	55.3	51.9	46.8	35.6	25.4	13.0	4.3	0.1
May 21	.2	4.4	14.8	27.8	40.5	53.6	59.9	63.0	64.3	60.5	51.2	40.6	27.6	14.9	4.3	.2
May 28	.3	5.6	16.9	32.0	45.1	54.8	63.8	65.4	64.4	58.1	51.0	40.8	28.9	16.8	5.7	.4
June 4	.5	5.6	15.8	30.2	40.2	50.3	56.0	59.5	58.5	55.7	47.6	38.6	25.7	14.4	5.5	.5
June 11	.5	4.9	14.1	27.0	39.1	51.1	58.2	58.7	60.6	60.9	50.9	39.6	27.3	15.6	5.8	.5
June 18	.6	6.0	16.2	28.7	40.4	50.5	56.5	59.1	59.0	54.2	46.8	37.5	27.9	16.7	5.8	.6
June 25	.6	6.5	17.3	31.7	44.1	54.8	62.5	67.3	67.6	61.2	54.4	42.6	29.7	16.3	5.9	.6
July 2	.5	5.8	17.2	30.8	43.3	54.0	62.0	67.4	66.0	63.0	55.5	41.7	30.0	17.5	6.5	.5
July 9	.4	5.4	14.4	25.3	37.9	49.0	57.0	62.3	61.8	58.3	49.5	40.6	28.6	16.2	5.6	.5
July 16	.3	5.4	14.8	26.7	37.7	49.3	55.7	61.0	60.2	55.3	48.5	38.3	25.9	14.4	5.0	.3
July 23	.2	3.8	15.2	27.2	39.5	51.3	56.4	61.1	62.9	58.7	50.6	40.1	31.9	14.8	4.1	.2
July 30	.1	3.2	12.1	25.4	38.3	48.6	57.2	61.5	63.5	58.1	51.1	38.4	26.6	14.2	3.6	.1
Aug. 6		2.4	11.1	22.5	34.8	43.9	51.6	53.2	55.3	52.1	46.3	35.0	22.7	11.3	2.6	
Aug. 13		2.0	9.5	22.0	33.2	44.7	52.5	54.8	56.2	54.8	45.9	35.1	23.2	10.8	2.1	
Aug. 20		1.5	8.4	20.1	31.3	41.7	49.0	54.6	54.5	49.8	46.2	36.9	21.7	10.1	1.8	
Aug. 27		1.0	7.6	19.0	31.1	41.9	49.7	54.8	53.9	52.3	43.7	30.6	19.6	7.9	.9	
Sept. 3		.6	6.0	16.6	27.5	38.9	44.8	51.8	50.3	45.9	37.7	29.8	17.9	7.5	.8	
Sept. 10		.4	5.3	15.6	26.4	36.1	43.4	47.4	48.4	43.1	37.5	28.1	17.0	6.0	.5	
Sept. 17		.2	4.4	16.9	29.0	39.8	46.9	50.3	50.3	46.5	40.2	28.6	15.3	4.8	.2	
Sept. 24			3.4	14.5	26.6	38.6	45.8	49.8	51.4	48.4	40.8	28.7	16.2	4.0		
Oct. 1			2.4	13.2	27.9	38.1	43.2	49.8	50.7	46.4	38.8	26.0	13.2	2.6		
Oct. 8			1.8	10.8	23.4	34.1	42.8	46.3	45.8	43.4	35.3	23.7	11.4	1.6		
Oct. 15			1.1	8.9	20.7	31.4	39.3	44.1	43.7	39.4	32.1	19.9	9.0	1.2		
Oct. 22			.8	6.8	17.3	30.0	37.8	41.3	40.9	37.7	29.8	18.4	7.4	.8		
Oct. 29			.5	5.5	15.4	24.9	31.7	35.8	36.4	32.6	25.8	16.1	5.9	.4		
Nov. 5			.3	4.4	13.7	22.2	30.2	33.1	33.4	28.5	23.0	13.8	4.6	.3		
Nov. 12			.1	3.1	10.4	19.0	26.0	30.0	29.6	24.6	18.8	10.9	3.4	.1		
Nov. 19				2.5	10.2	19.8	27.0	31.0	30.5	25.6	19.8	10.9	2.8			
Nov. 26				1.8	8.6	18.1	24.3	26.5	26.9	23.4	16.0	9.6	2.3			
Dec. 3				1.6	8.3	17.1	24.4	30.2	29.5	25.5	18.1	9.4	1.8			
Dec. 10				1.2	6.4	13.4	17.4	20.1	19.7	17.0	12.8	6.8	1.3			
Dec. 17				1.3	6.9	14.6	20.8	24.4	24.2	20.6	15.0	7.6	1.4			
Dec. 24 [1]				1.3	7.3	15.0	20.9	23.5	24.5	21.2	15.5	8.1	1.8			
Means	.1	1.5	6.0	14.6	24.7	35.0	42.0	45.8	45.8	42.1	35.1	25.3	15.0	6.4	1.6	.1

[1] 8-day period.

TABLE 4.—*Ratio of direct solar radiation on a horizontal surface to diffuse sky radiation during cloudless days, Washington, D. C.*

Solar zenith distance	30°	60°	78.7°
Air mass	1.15	2.0	5.0
Winter	8.1	5.0	1.7
Summer	5.2	3.1	1.5
Mean	6.65	4.05	1.6

TABLE 5.—*Monthly mean intensities of direct solar radiation at normal incidence, gram calories per square centimeter per minute*

[Lines (1) and (2) are the a. m. and p. m. intensities, respectively, at the given air masses, and line (3) is their average; line (4) is the average reduced to mean solar distance, and line (5) its expression as a percentage of the solar constant; (6) is the atmospheric transmission computed by equation (1) in the text]

WASHINGTON, D. C., OCTOBER 1914 TO DECEMBER 1936, INCLUSIVE

Air mass	1.0	2.0	3.0	4.0	5.0	Air mass	1.0	2.0	3.0	4.0	5.0
January:						July:					
(1)		1.24	1.02	0.86	0.75	(1)	1.21	0.92	0.78	0.68	0.58
(2)		1.24	1.05	.90	.81	(2)		1.00	.79	.68	(.75)
(3)		1.24	1.03	.88	.77	(3)	1.21	.93	.78	.68	.59
(4)		1.20	1.00	.85	.75	(4)	1.25	.96	.80	.70	.61
(5)		62	51	44	39	(5)	64	49	41	36	31
(6)		.786	.800	.814	.826	(6)	.661	.704	.746	.773	.793
February:						August:					
(1)	1.56	1.20	1.00	.83	.73	(1)	1.25	.94	.77	.69	.63
(2)		1.20	1.00	.86	.77	(2)		1.03	.87	.73	.63
(3)	1.56	1.20	1.00	.84	.74	(3)	1.25	.96	.79	.70	.63
(4)	1.53	1.17	.98	.82	.72	(4)	1.28	.98	.81	.72	.65
(5)	79	60	51	42	37	(5)	66	51	42	37	34
(6)	.784	.777	.795	.806	.821	(6)	.677	.720	.754	.785	.803
March:						September:					
(1)	1.42	1.15	.95	.81	.73	(1)	1.31	1.04	.86	.75	.69
(2)		1.13	.94	.79	.70	(2)		1.07	.87	.75	.69
(3)	1.42	1.15	.95	.80	.72	(3)	1.31	1.05	.86	.75	.69
(4)	1.41	1.14	.94	.79	.71	(4)	1.32	1.06	.87	.76	.70
(5)	73	59	48	41	37	(5)	68	55	45	39	36
(6)	.724	.766	.785	.799	.818	(6)	.682	.740	.765	.791	.815
April:						October:					
(1)	1.36	1.08	.89	.70	.60	(1)	1.42	1.13	.97	.85	.75
(2)		1.09	.89	.74	.63	(2)		1.13	.95	.82	.74
(3)	1.36	1.09	.89	.77	.68	(3)	1.42	1.13	.96	.84	.75
(4)	1.37	1.09	.90	.78	.69	(4)	1.41	1.12	.95	.83	.74
(5)	71	56	46	40	36	(5)	73	58	49	43	38
(6)	.711	.753	.776	.798	8.14	(6)	.728	.761	.79	.810	.826
May:						November:					
(1)	1.27	1.00	.83	.72	.63	(1)	1.48	1.19	1.01	.87	.75
(2)		.93	.88	.66	.58	(2)		1.18	1.00	.85	.74
(3)	1.27	.99	.82	.71	.63	(3)	1.48	1.18	1.00	.86	.75
(4)	1.30	1.01	.84	.72	.64	(4)	1.45	1.16	.98	.84	.74
(5)	67	52	43	37	33	(5)	75	60	51	43	38
(6)	.669	.722	.756	.782	.802	(6)	.746	.771	.796	.811	.821
June:						December:					
(1)	1.25	.94	.78	.67	.54	(1)	1.51	1.23	1.05	.90	.78
(2)		.94	.72	.66		(2)		1.29	1.04	.91	.79
(3)	1.25	.94	.78	.67	.54	(3)	1.51	1.23	1.04	.91	.79
(4)	1.29	.97	.80	.69	.56	(4)	1.46	1.19	1.01	.89	.76
(5)	67	50	41	36	29	(5)	75	61	52	46	39
(6)	.665	.707	.746	.778	.785	(6)	.754	.784	.809	.817	.830

MADISON, WIS., JULY 1910 TO DECEMBER 1936, INCLUSIVE

Air mass	1.0	2.0	3.0	4.0	5.0	Air mass	1.0	2.0	3.0	4.0	5.0
January:						July:					
(1)	1.56	1.36	1.21	1.06	0.96	(1)	1.31	1.07	0.92	0.78	0.67
(2)		1.42	1.15	1.07		(2)		1.04	.91	.78	
(3)	1.56	1.36	1.17	1.06	.96	(3)	1.31	1.06	.92	.78	.67
(4)	1.51	1.32	1.13	1.02	.94	(4)	1.35	1.09	.95	.80	.69
(5)	79	69	59	54	48	(5)	70	56	49	41	36
(6)	.778	.824	.836	.853	.863	(6)	.698	.751	.788	.803	.814
February:						August:					
(1)	1.58	1.36	1.20	1.07	.93	(1)	1.32	1.09	.97	.81	.71
(2)		1.36	1.17	1.12	(1.11)	(2)		1.05	.87	.82	.61
(3)	1.58	1.36	1.19	1.07	.94	(3)	1.32	1.08	.93	.81	.69
(4)	1.54	1.33	1.16	1.04	.92	(4)	1.35	1.11	.95	.83	.70
(5)	79	69	60	54	47	(5)	70	57	49	43	36
(6)	.794	.827	.843	.856	.861	(6)	.698	.756	.789	.804	.817
March:						September:					
(1)	1.58	1.31	1.16	1.02	.92	(1)	1.40	1.16	1.03	.91	.84
(2)		1.29	1.17	1.07	.93	(2)		1.18	1.03	.85	.89
(3)	1.58	1.30	1.16	1.03	.92	(3)	1.40	1.17	1.03	.90	.84
(4)	1.56	1.29	1.14	1.02	.91	(4)	1.41	1.18	1.04	.91	.85
(5)	80	66	59	53	47	(5)	73	61	54	47	44
(6)	.806	.814	.839	.851	.859	(6)	.729	.780	.813	.827	.848
April:						October:					
(1)	1.44	1.19	1.03	.91	.84	(1)	1.43	1.20	1.05	.92	.80
(2)		1.18	1.08	.87	.68	(2)		1.20	1.02	.90	.64
(3)	1.44	1.19	1.04	.91	.79	(3)	1.43	1.20	1.05	.92	.78
(4)	1.46	1.20	1.05	.92	.80	(4)	1.42	1.19	1.04	.91	.77
(5)	75	62	54	47	41	(5)	73	61	54	47	40
(6)	.747	.786	.814	.829	.837	(6)	.733	.784	.814	.829	.833
May:						November:					
(1)	1.37	1.11	1.01	.82	.80	(1)	1.54	1.31	1.16	1.00	.89
(2)		1.04	.89			(2)		1.33	1.12	.84	(.24)
(3)	1.37	1.10	1.00	.82	.79	(3)	1.54	1.31	1.14	1.00	.88
(4)	1.40	1.12	1.02	.84	.81	(4)	1.51	1.29	1.12	.98	.86
(5)	72	58	53	43	42	(5)	78	66	58	51	44
(6)	.722	.761	.808	.811	.839	(6)	.777	.813	.831	.843	.850
June:						December:					
(1)	1.33	1.04	.98	.86	.76	(1)	1.52	1.36	1.21	1.08	.96
(2)		1.09	.92			(2)			1.25	1.02	
(3)	1.33	1.05	.98	.86	.76	(3)	1.52	1.36	1.22	1.07	.96
(4)	1.37	1.08	1.01	.89	.78	(4)	1.47	1.32	1.18	1.04	.93
(5)	71	56	52	46	40	(5)	76	68	61	54	48
(6)	.707	.747	.805	.822	.834	(6)	.759	.824	.848	.855	.863

TABLE 5.—*Monthly mean intensities of direct solar radiation at normal incidence, gram calories per square centimeter per minute*—Continued

[Lines (1) and (2) are the a. m. and p. m. intensities, respectively, at the given air masses, and line (3) is their average; line (4) is the average reduced to mean solar distance, and line (5) its expression as a percentage of the solar constant; (6) is the atmospheric transmission computed by equation (1) in the text]

LINCOLN, NEBR., NOVEMBER 1911 TO DECEMBER 1936, INCLUSIVE

Air mass	1.0	2.0	3.0	4.0	5.0	Air mass	1.0	2.0	3.0	4.0	5.0
January:						July:					
(1)		1.38	1.19	1.05	0.93	(1)	1.34	1.08	0.92	0.79	0.71
(2)		1.35	1.18	1.05	.93	(2)		1.07	.89	.76	.70
(3)		1.37	1.18	1.05	.93	(3)	1.34	1.08	.90	.77	.70
(4)		1.32	1.14	1.01	.90	(4)	1.38	1.11	.93	.79	.72
(5)		70	60	53	47	(5)	71	57	48	41	37
(6)		.827	.838	.851	.856	(6)	.714	.758	.783	.800	.836
February:						August:					
(1)	1.54	1.37	1.16	1.02	.93	(1)	1.31	1.09	.91	.78	.68
(2)		1.35	1.16	1.02	.90	(2)		1.07	.89	.75	.64
(3)	1.54	1.36	1.16	1.02	.92	(3)	1.31	1.09	.90	.77	.66
(4)	1.50	1.33	1.13	1.00	.90	(4)	1.34	1.11	.92	.79	.68
(5)	77	69	59	52	46	(5)	69	57	47	41	35
(6)	.774	.827	.836	.846	.857	(6)	.693	.760	.781	.799	.810
March:						September:					
(1)	1.53	1.28	1.09	.94	.84	(1)	1.42	1.13	.97	.84	.74
(2)		1.28	1.09	.94	.81	(2)		1.16	.98	.84	.73
(3)	1.53	1.28	1.09	.94	.82	(3)	1.42	1.14	.97	.84	.74
(4)	1.51	1.27	1.08	.93	.81	(4)	1.43	1.15	.98	.85	.75
(5)	78	65	56	48	42	(5)	74	59	51	44	39
(6)	.775	.808	.822	.832	.838	(6)	.740	.771	.796	.813	.823
April:						October:					
(1)	1.45	1.19	.97	.82	.71	(1)	1.48	1.29	1.09	.93	.83
(2)		1.16	.96	.82	.69	(2)		1.25	1.08	.94	.83
(3)	1.45	1.18	.97	.82	.70	(3)	1.48	1.27	1.09	.94	.83
(4)	1.46	1.19	.98	.83	.71	(4)	1.47	1.26	1.08	.93	.82
(5)	75	61	51	43	37	(5)	76	65	56	48	42
(6)	.753	.783	.796	.808	.817	(6)	.759	.807	.824	.832	.843
May:						November:					
(1)	1.38	1.11	.93	.78	.66	(1)	1.55	1.35	1.18	1.03	.92
(2)		1.10	.90	.81	.68	(2)		1.35	1.18	1.04	.92
(3)	1.38	1.11	.92	.79	.67	(3)	1.55	1.35	1.18	1.03	.92
(4)	1.41	1.13	.94	.81	.69	(4)	1.52	1.32	1.16	1.01	.90
(5)	73	58	48	42	36	(5)	78	67	60	52	46
(6)	.727	.765	.786	.803	.812	(6)	.782	.825	.841	.849	.858
June:						December:					
(1)	1.36	1.11	.94	.79	.76	(1)	1.64	1.38	1.23	1.09	.94
(2)		1.11	.92	.79	.68	(2)			1.20	1.07	.96
(3)	1.36	1.11	.93	.79	.71	(3)	1.64	1.38	1.22	1.08	.95
(4)	1.40	1.14	.96	.81	.73	(4)	1.59	1.34	1.18	1.05	.92
(5)	72	59	49	42	38	(5)	82	69	61	54	47
(6)	.723	.768	.791	.805	.823	(6)	.819	.830	.848	.857	.861

BLUE HILL, MASS., SEPTEMBER 1933 TO DECEMBER 1936, INCLUSIVE

Air mass	1.0	2.0	3.0	4.0	5.0	Air mass	1.0	2.0	3.0	4.0	5.0
January:						July:					
(1)		1.32	1.14	1.02	0.90	(1)	1.28	1.06	0.98	0.85	0.76
(2)		1.34	1.18	1.09	.98	(2)		1.03	.95	.84	.76
(3)		1.32	1.16	1.05	.94	(3)	1.28	1.06	.98	.85	.76
(4)		1.28	1.12	1.02	.91	(4)	1.32	1.09	1.01	.88	.78
(5)		66	58	53	47	(5)	68	56	52	46	40
(6)		.811	.833	.851	.859	(6)	.682	.751	.805	.820	.835
February:						August:					
(1)	1.47	1.26	1.06	.98	.85	(1)	1.26	1.08	.95	.83	.70
(2)		1.26	1.14	1.06	1.00	(2)		1.00	.96	.72	.68
(3)	1.47	1.26	1.10	1.03	.94	(3)	1.26	1.06	.96	.77	.68
(4)	1.44	1.23	1.08	1.01	.92	(4)	1.29	1.09	.98	.79	.70
(5)	74	64	56	52	47	(5)	66	56	51	41	35
(6)	.739	.796	.821	.848	.861	(6)	.666	.740	.798	.790	.815
March:						September:					
(1)	1.40	1.19	1.03	.93	.82	(1)	1.36	1.17	1.04	.95	.82
(2)		1.18	1.00	.93	.81	(2)		1.13	.93	.84	.75
(3)	1.40	1.19	1.03	.93	.82	(3)	1.36	1.15	1.00	.91	.78
(4)	1.39	1.18	1.02	.92	.81	(4)	1.37	1.16	1.01	.92	.79
(5)	72	60	53	47	42	(5)	71	60	52	47	41
(6)	.714	.779	.806	.830	.840	(6)	.708	.774	.805	.830	.835
April:						October:					
(1)	1.40	1.16	1.10	.94	.86	(1)	1.42	1.26	1.14	1.03	1.00
(2)		1.10	1.00	.95	(.85)	(2)		1.22	1.03	.89	.75
(3)	1.40	1.14	1.04	.94	.86	(3)	1.42	1.24	1.08	.96	.89
(4)	1.41	1.15	1.05	.95	.87	(4)	1.41	1.23	1.07	.95	.88
(5)	73	59	54	49	45	(5)	73	63	55	49	45
(6)	.726	.769	.814	.836	.851	(6)	.726	.797	.821	.838	.855
May:						November:					
(1)	1.37	1.13	1.11	1.00	.94	(1)		1.27	1.15	1.08	1.01
(2)		1.10	.89	.80	(.88)	(2)		1.27	1.14	.98	.79
(3)	1.37	1.12	1.03	.94	.91	(3)		1.27	1.14	1.03	.91
(4)	1.40	1.14	1.05	.96	.93	(4)		1.24	1.11	1.01	.89
(5)	72	59	54	49	48	(5)		64	57	52	46
(6)	.720	.768	.815	.839	.863	(6)		.799	.831	.848	.856
June:						December:					
(1)	1.29	1.08	1.03	.86		(1)		1.39	1.20	1.11	.95
(2)		1.07	.90	.88	.77	(2)		1.30	1.19	1.04	.95
(3)	1.29	1.07	.96	.88	.77	(3)		1.35	1.19	1.07	.95
(4)	1.33	1.10	.99	.91	.79	(4)		1.31	1.15	1.04	.92
(5)	69	57	51	47	41	(5)		68	59	54	47
(6)	.686	.758	.799	.827	.836	(6)		.821	.841	.855	.862

TABLE 6.—*Values of the air mass, m, at different altitudes, h, of the sun, computed by Bemporad's formula*

h	90°	80°	75°	70°	69°	68°	67°	66°	65°	64°
m	1.00	1.02	1.04	1.06	1.07	1.08	1.09	1.09	1.10	1.11
h	63°	62°	61°	60°	59°	58°	57°	56°	55°	54°
m	1.12	1.13	1.14	1.15	1.17	1.18	1.19	1.20	1.22	1.24
h	53°	52°	51°	50°	49°	48°	47°	46°	45°	44°
m	1.25	1.27	1.28	1.30	1.32	1.34	1.37	1.39	1.41	1.44
h	43°	42°	41°	40°	39°	38°	37°	36°	35°	34°
′ ′ °										
52-57=0.9	1.44	1.47	1.49	1.53	1.56	1.59	1.62	1.66	1.70	1.74
46-51=0.8	1.44	1.47	1.50	1.53	1.56	1.59	1.63	1.67	1.71	1.75
40-45=0.7	1.45	1.47	1.50	1.53	1.56	1.60	1.63	1.67	1.71	1.75
34-39=0.6	1.45	1.48	1.50	1.53	1.57	1.60	1.63	1.67	1.71	1.76
28-33=0.5	1.45	1.48	1.51	1.54	1.57	1.60	1.64	1.68	1.72	1.76
22-27=0.4	1.45	1.48	1.51	1.54	1.57	1.61	1.64	1.68	1.72	1.77
16-21=0.3	1.46	1.48	1.51	1.54	1.58	1.61	1.65	1.69	1.72	1.77
10-15=0.2	1.46	1.49	1.52	1.55	1.58	1.61	1.65	1.69	1.73	1.78
4- 9=0.1	1.46	1.49	1.52	1.55	1.58	1.62	1.65	1.69	1.74	1.78
57- 3=0.0	1.46	1.49	1.52	1.55	1.59	1.62	1.66	1.70	1.74	1.78
h	33°	32°	31°	30°	29°	28°	27°	26°	25°	24°
′ ′ °										
52-57=0.9	1.79	1.84	1.89	1.94	2.00	2.06	2.13	2.20	2.28	2.36
46-51=0.8	1.79	1.84	1.89	1.95	2.01	2.07	2.14	2.21	2.29	2.37
40-45=0.7	1.80	1.85	1.90	1.95	2.01	2.08	2.14	2.22	2.30	2.38
34-39=0.6	1.80	1.86	1.90	1.96	2.02	2.08	2.15	2.23	2.31	2.39
28-33=0.5	1.81	1.86	1.91	1.96	2.02	2.09	2.16	2.24	2.32	2.40
22-27=0.4	1.81	1.87	1.92	1.97	2.03	2.10	2.17	2.25	2.33	2.41
16-21=0.3	1.82	1.87	1.92	1.98	2.04	2.10	2.17	2.25	2.33	2.42
10-15=0.2	1.82	1.87	1.93	1.98	2.05	2.11	2.18	2.26	2.34	2.43
3- 9=0.1	1.83	1.88	1.93	1.99	2.06	2.12	2.19	2.27	2.35	2.44
57- 3=0.0	1.83	1.88	1.94	2.00	2.06	2.12	2.20	2.28	2.36	2.45
h	23°	22°	21°	20°	19°	18°	17°	16°	15°	14°
′ ′ °										
52-57=0.9	2.46	2.56	2.66	2.78	2.92	3.06	3.23	3.41	3.61	3.84
46-51=0.8	2.47	2.57	2.68	2.80	2.93	3.08	3.24	3.43	3.63	3.86
40-45=0.7	2.48	2.58	2.69	2.81	2.95	3.10	3.26	3.45	3.65	3.89
34-39=0.6	2.49	2.59	2.70	2.82	2.96	3.11	3.28	3.47	3.68	3.92
28-33=0.5	2.50	2.60	2.71	2.84	2.98	3.13	3.30	3.49	3.70	3.94
22-27=0.4	2.51	2.61	2.72	2.85	2.99	3.14	3.31	3.51	3.72	3.97
16-21=0.3	2.52	2.62	2.74	2.86	3.00	3.16	3.33	3.53	3.74	3.99
10-15=0.2	2.53	2.63	2.75	2.88	3.02	3.18	3.35	3.55	2.77	4.02
4- 9=0.1	2.54	2.64	2.76	2.89	3.03	3.19	3.37	3.57	3.79	4.05
57- 3=0.0	2.55	2.65	2.77	2.90	3.05	3.21	3.39	3.59	3.82	4.08
h	13°	12°	11°	10°	9°					
′ ′ °										
52-57=0.9	4.10	4.40	4.75	5.16	5.64					
46-51=0.8	4.13	4.44	4.79	5.21	5.70					
40-45=0.7	4.16	4.47	4.83	5.26	5.76					
34-39=0.6	4.19	4.50	4.87	5.30	5.82					
28-33=0.5	4.22	4.54	4.91	5.35	5.87					
22-27=0.4	4.25	4.57	4.95	5.40	5.93					
16-21=0.3	4.28	4.61	4.99	5.45	5.99					
10-15=0.2	4.31	4.64	5.03	5.50	6.06					
4- 9=0.1	4.34	4.68	5.08	5.55	6.12					
57- 3=0.0	4.37	4.72	5.12	5.60	6.19					

TABLE 7.—*Maximum observed normal incidence intensities, gram calories per square centimeter per minute*

Month	Washington		Madison		Lincoln		Santa Fe		Mount Weather	
	Observed	Reduced[1]	Observed	Reduced[1]	Observed	Reduced[1]	Observed	Reduced[1]	Observed	Reduced[1]
January	1.45	1.41	1.56	1.44	1.53	1.48	1.66	1.61	1.37	1.32
February	1.59	1.55	1.57	1.54	1.58	1.54	1.65	1.62	1.48	1.45
March	1.53	1.50	1.50	1.57	1.56	1.54	1.66	1.63	1.48	1.46
April	1.51	1.52	1.58	1.58	1.58	1.59	1.64	1.64	1.45	1.46
May	1.46	1.50	1.49	1.52	1.53	1.56	1.61	1.63	1.50	1.53
June	1.47	1.52	1.45	1.49	1.49	1.53	1.57	1.62	1.47	1.52
July	1.47	1.52	1.46	1.50	1.44	1.49	1.45	1.50	1.48	1.53
August	1.43	1.47	1.46	1.50	1.49	1.53	1.56	1.59	1.45	1.48
September	1.49	1.51	1.46	1.48	1.48	1.49	1.62	1.63	1.50	1.51
October	1.51	1.51	1.46	1.45	1.53	1.52	1.59	1.58	1.48	1.47
November	1.49	1.45	1.42	1.40	1.56	1.53	1.63	1.60	1.43	1.40
December	1.48	1.43	1.47	1.42	1.51	1.46	1.61	1.56	1.40	1.36
Year	1.49	1.49	1.50	1.49	1.54	1.54	1.60	1.60	1.50	1.54
Range	.16	.14	.18	.18	.14	.13	.11	.14	.13	.12

[1] To mean solar distance.

TABLE 8.—*Illumination equivalent of 1 gram calorie per minute per square centimeter of total solar and sky radiation at different solar altitudes*

Air mass	1.06	1.1	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
Solar altitude	70.0°	65.0°	42.7°	30.0°	23.5°	19.3°	16.4°	14.3°	12.6°	11.3°	10.2°
MOUNT WEATHER, VA. (1919)											
Foot candles	------	6,720	6,600	5,580	5,310	5,120	4,780	4,670	4,610	4,600	4,460
WASHINGTON, D. C. (1921-22)											
Foot candles	7,040	7,020	6,880	6,740	6,650	6,580	6,520	6,460	6,410	6,370	6,320

TABLE 9.—*Sky polarization, percent, sun at zenith distance 60°, Washington, D. C.*

(Average of values observed during month)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1914	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	65	62
1915	63	-----	65	57	50	52	45	45	54	64	62	60
1916	64	61	64	52	51	46	54	50	56	56	54	58
1917	61	65	60	48	48	44	40	50	59	51	50	51
1918	-----	47	54	60	52	46	55	56	56	60	59	58
1919	55	53	62	56	-----	39	48	50	59	55	53	62
1920	56	48	53	54	57	48	51	-----	58	56	63	60
1921	59	64	54	44	56	52	38	54	54	63	64	55
1922	57	55	56	56	60	44	50	57	57	57	60	58
1923	66	63	56	52	51	40	50	47	57	56	60	64
1924	56	58	55	58	49	38	51	56	50	62	62	55
1925	-----	51	56	60	48	49	43	51	55	64	63	64
1926	-----	58	61	65	60	53	53	54	51	57	62	65
1927	63	61	54	54	56	57	56	44	57	55	57	52
1928	57	59	60	57	54	50	46	52	52	50	62	56
1929	58	63	62	58	51	48	53	54	51	53	52	52
1930	-----	63	58	46	53	54	51	57	50	52	52	59
1931	56	61	56	59	56	59	53	54	56	63	60	61
1932	62	-----	58	58	54	60	62	60	57	60	58	55
1933	58	52	49	54	55	46	57	57	56	59	57	60
1934	61	-----	61	57	46	56	55	58	54	54	54	54
1935	55	56	59	59	60	58	56	-----	58	59	58	57
1936	-----	-----	60	61	61	61	56	58	55	61	55	55
Mean	59.5	59.2	57.9	55.7	53.7	50.0	51.0	53.4	55.1	57.6	58.3	59.6

MAXIMUM VALUE OBSERVED DURING MONTH[1]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1914	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	72	69
1915	68	-----	71	67	53	63	57	49	72	69	66	66
1916	66	65	70	58	58	59	64	66	65	61	59	63
1917	66	69	65	66	62	50	49	56	66	63	60	52
1918	-----	65	64	66	59	47	64	62	62	64	64	62
1919	60	65	66	64	-----	43	59	65	67	63	66	66
1920	63	52	65	59	64	54	57	-----	67	64	65	60
1921	65	64	64	63	63	59	51	61	69	72	65	65
1922	62	57	62	59	63	51	61	70	65	74	63	64
1923	66	70	63	64	67	56	59	58	70	67	70	64
1924	67	65	63	62	56	55	69	64	52	68	64	56
1925	-----	58	65	66	56	60	49	56	67	71	66	69
1926	-----	60	66	66	65	56	56	58	-----	60	67	66
1927	65	62	68	60	56	59	57	47	66	57	57	57
1928	61	63	63	59	63	56	48	54	55	56	67	60
1929	59	64	68	62	60	52	61	58	56	66	55	64
1930	-----	66	61	60	62	56	60	62	47	55	52	62
1931	59	64	60	66	58	64	58	54	64	70	66	65
1932	66	-----	64	63	59	68	66	65	65	64	66	63
1933	64	56	54	63	56	52	59	60	64	63	63	62
1934	63	-----	65	62	58	57	61	60	60	60	60	64
1935	60	56	63	64	63	60	61	-----	62	62	63	63
1936	-----	-----	61	64	63	63	58	61	64	57	58	60
Mean	63.5	62.3	64.1	62.9	60.7	56.4	58.4	59.3	63.1	63.9	63.2	62.7

[1] Number of days on which observations are taken varies from month to month, and is given in reports published monthly in REVIEW.

TABLE 10.—*Sky polarization, percent, sun at zenith distance 60°, Madison, Wis.*

AVERAGE OF VALUES OBSERVED DURING MONTH [1]

Year	January	February	March	April	May	June	July	August	September	October	November	December
1917	-----	-----	-----	57	54	59	59	66	66	67	59	71
1918	-----	-----	61	63	59	64	65	62	67	64	66	-----
1919	68	66	60	60	60	47	56	61	67	66	70	-----
1920	-----	-----	62	66	56	70	55	58	69	63	76	71
1921	72	65	69	60	66	64	65	57	69	68	70	72
1922	-----	-----	61	61	60	53	70	55	64	70	71	-----
1923	-----	-----	-----	58	61	52	59	66	65	64	-----	72
1924	51	-----	-----	64	58	60	60	65	68	62	65	67
1925	-----	-----	56	55	49	58	58	55	58	60	61	-----
1926	-----	-----	-----	60	53	60	49	55	70	67	-----	-----
1927	-----	-----	61	62	57	60	57	64	69	69	73	-----
1928	-----	-----	-----	67	58	66	61	67	66	69	75	-----
1929	-----	-----	73	63	54	56	62	51	59	60	65	-----
1930	-----	-----	-----	58	55	57	61	48	60	55	62	71
1931	-----	-----	66	55	53	54	60	62	61	65	72	72
1932	-----	-----	-----	60	60	62	60	59	60	58	67	-----
1933	-----	-----	-----	59	59	60	64	63	68	69	64	72
1934	-----	-----	60	56	52	65	56	47	57	52	53	-----
1935	-----	-----	-----	51	59	62	58	54	60	69	67	61
1936	-----	-----	-----	63	60	64	50	44	62	60	60	66
Mean	63.7	65.5	62.9	59.9	57.2	59.6	59.4	58.0	64.2	63.6	66.4	69.5

MAXIMUM VALUE OBSERVED DURING MONTH [1]

Year	January	February	March	April	May	June	July	August	September	October	November	December
1917	-----	-----	-----	67	64	66	71	71	76	71	71	73
1918	-----	-----	71	67	65	69	72	71	74	69	73	-----
1919	70	68	65	66	67	57	68	71	73	71	73	-----
1920	-----	-----	67	68	67	72	69	72	75	76	79	71
1921	76	73	72	67	70	66	70	70	76	74	70	72
1922	-----	-----	61	70	66	71	72	72	74	74	72	-----
1923	-----	-----	-----	65	70	65	61	74	71	68	-----	72
1924	-----	-----	-----	69	64	71	70	71	71	66	66	67
1925	-----	-----	64	60	60	62	64	65	66	67	66	-----
1926	-----	-----	-----	-----	63	64	65	64	72	70	-----	-----
1927	-----	-----	69	65	64	65	69	70	73	76	73	-----
1928	-----	-----	-----	72	68	70	72	77	73	77	76	-----
1929	-----	-----	73	67	63	61	65	63	69	70	72	-----
1930	-----	-----	-----	70	63	69	68	59	70	61	68	71
1931	-----	-----	66	66	60	61	70	70	71	76	75	77
1932	-----	-----	-----	65	66	73	67	64	69	60	67	-----
1933	-----	-----	-----	61	70	71	72	74	77	76	65	74
1934	-----	-----	60	64	61	70	64	61	63	57	57	-----
1935	-----	-----	-----	-----	70	67	66	58	76	77	69	61
1936	-----	-----	-----	71	67	66	59	57	69	64	70	66
Mean	73.0	70.5	66.8	66.7	64.4	67.0	67.8	67.7	71.9	70.0	70.1	70.4

[1] Number of days on which observations are taken varies from month to month, and is given in reports published monthly in REVIEW.

TABLE 11.—*Comparison of blueness of sky with sky polarization and visibility, Washington, D. C.*

Blueness of sky	Percent of polarization	Visibility, miles	Number of observations
2	11.0	1.0	1
3	44.1	10.5	11
4	51.7	16.5	145
5	57.0	25.6	292
6	59.3	38.1	120
7	62.1	43.9	15
8	65.5	50.0	2

TABLE 12.—*Dust content of the atmosphere at American University, District of Columbia, at 8 a. m., particles per cubic centimeter*

MONTHLY MEANS

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual means
1922	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1,228	-----
1923	1,061	905	540	476	393	-----	397	388	386	395	451	557	540
1924	719	533	409	645	376	420	539	326	335	598	1,110	1,159	597
1925	723	1,092	909	753	416	507	480	484	514	608	787	1,444	726
1926	1,631	1,517	1,370	755	573	578	542	532	565	692	851	1,056	888
1927	1,011	1,116	939	721	729	607	933	760	859	1,021	1,097	1,176	914
1928	1,455	1,450	1,232	856	668	596	757	675	774	1,082	979	1,227	978
1929	1,419	1,086	652	610	621	469	549	626	638	616	858	881	752
1930	898	736	668	753	614	544	573	828	866	1,020	995	875	781
1931	906	951	809	815	608	631	-----	-----	-----	-----	-----	-----	-----
Average	1,091	1,043	836	709	555	544	596	577	617	754	891	1,047	772

MAXIMA

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual means
1922	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	2,088	-----
1923	3,680	2,050	1,155	1,182	905	-----	793	794	812	853	1,023	2,340	1,394
1924	2,403	1,964	1,280	1,661	1,154	1,250	1,953	796	823	1,366	1,987	2,551	1,595
1925	1,352	2,370	2,247	7,077	781	991	1,016	1,037	1,109	1,432	1,558	3,106	2,006
1926	3,828	2,995	2,990	1,527	1,042	1,035	985	941	1,073	1,426	3,975	2,388	2,018
1927	3,511	2,474	1,877	1,588	1,529	1,560	1,651	1,443	1,672	3,133	2,566	2,984	2,168
1928	3,620	3,557	2,617	2,039	1,575	1,434	1,308	1,302	1,493	2,772	2,751	4,116	2,382
1929	3,620	1,982	1,583	1,153	1,082	897	922	976	1,010	1,098	1,628	1,606	1,463
1930	3,780	1,512	1,176	1,166	1,701	855	1,052	1,323	1,426	2,066	1,953	1,779	1,649
1931	1,617	1,649	1,352	1,434	846	1,073	-----	-----	-----	-----	-----	-----	-----
Average	3,046	2,284	1,810	2,089	1,179	1,137	1,210	1,076	1,177	1,761	2,180	2,551	1,792
Absolute maximum	3,828	3,557	2,990	7,077	1,701	1,560	1,953	1,443	1,672	3,133	3,975	4,116	-----

MINIMA

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual means
1922	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	298	-----
1923	214	105	113	113	65	-----	90	110	59	96	71	90	108
1924	124	97	76	151	124	155	124	87	97	155	113	124	118
1925	57	77	87	202	149	197	132	143	118	130	124	344	147
1926	160	298	223	227	187	214	218	145	132	82	76	145	176
1927	155	185	145	138	225	122	288	187	218	99	172	143	173
1928	160	254	162	174	126	202	384	132	126	334	120	109	190
1929	160	200	101	242	134	128	170	191	176	124	323	204	179
1930	361	253	237	241	134	178	150	144	278	384	231	376	247
1931	372	369	174	233	275	216	-----	-----	-----	-----	-----	-----	-----
Average	196	204	146	191	158	176	194	132	150	176	154	204	174
Absolute minimum	57	77	76	113	65	122	90	87	59	82	71	90	-----

FLOODS IN THE SACRAMENTO VALLEY, CALIF., DECEMBER 1937

By E. H. FLETCHER

[Weather Bureau, Sacramento, Calif., January 1938]

December 1937 will be epochal in the history of the floods of the Sacramento Valley in that it produced the highest stages in the river system above the mouth of the American River since the beginning of Weather Bureau records in 1904, and, from all indications, exceeded the high water of 1862 in the upper valley.

During the first week in October there were unprecedentedly heavy rains, for so early in the season, in the upper Sacramento River basin. A long period of protracted, heavy rainfall followed in November and resulted in the highest water of record for the season in that river.

In past years no great flood has ever been known to occur in December. This year, however, the ground was well saturated at the end of November and the stream channels and bypasses were still carrying considerable water. This condition, together with the fact that the earlier fallen snow had receded to high altitudes, constituted a favorable situation for a high percentage of immediate run-off from rainfall, there being no retarding influence occasioned by a heavy snow cover.

On December 9, a center of low barometric pressure of unusual potentialities was located about 700 miles off

the central California coast, and a forecast was issued to the effect that a general rise in all the streams of the Sacramento system was imminent. Rainfall began generally before noon of that day.

The weather map, on the next morning, showed a storm of record magnitude and almost of hurricane intensity (barometer 28.1 inches at its center) off the coast of Washington and Oregon. Maritime tropical air flowed rapidly across California at gale velocity and converged against the high mountain barriers that form the eastern and northern limits of the Sacramento basin. The moisture-laden air, with record high temperatures for December, produced torrential rains over the headwaters of the upper Sacramento, Feather, and Yuba Rivers, and to a slightly lesser extent over the American and the eastern tributaries of the San Joaquin.

Early on the 10th, warnings were issued advising of the favorable conditions for a flood, especially in Tehama County. That morning the river at Red Bluff was 11.8 feet, but by evening it had risen to 20 feet. On account of the extremely flashy nature of the streams in the upper Sacramento Valley, it is a difficult problem to forecast river stages in that section if the local creeks are discharging enormous volumes of water. The rise in the upper valley is rapid and may occur in advance of the upstream water, as indicated on the gage at Kennett.

Downieville, a town of about 400 and the county seat of Sierra County, on the North Fork of the Yuba River, suffered partial destruction on the 10th when water from a downpour of cloudburst intensity in the deep canyons above, swept through the lower part of this mountain town, carrying away a number of buildings and destroying the highway bridge at that point. Later reports indicated that the flow of water was obstructed by debris lodged against the concrete highway bridge just below the town, causing the water to back up into the streets. The damage to Downieville is estimated at $200,000, and to the surrounding area, $80,000.

The Sacramento River at Kennett crested on December 11 at 2 a. m. with a stage of 29.0 feet, which has been exceeded only in 1907 by a record stage of 33.2 feet, and in 1909 by 31.8 feet. Kennett is an outpost station in the Sacramento River Canyon where a 20-foot rise may occur overnight; and little or no damage results, except that the roadway near Big Backbone Creek becomes flooded at a stage in excess of 25 feet.

Similarly, at the outpost river station of Colgate, in a deep canyon on the North Fork of the Yuba River, the water rose with great rapidity to 22.0 feet, which is 1.0 foot above the March 1928 crest and 1.0 foot below the record high stage in 1907.

At Red Bluff, the Sacramento River, heightened by additional heavy flows from numerous important creeks from both the Coast Range and Mount Lassen area, rose rapidly to a crest of 32.0 feet on the morning of the 11th, which is 9 feet above the flood stage and 1.5 feet above the previous high record established in February 1909. Extensive inundation of the lower lands occurred as the highest flood wave of record spread southward from Red Bluff to the mouth of Stony Creek.

The towns of Gerber, Tehama, and Vina were almost completely flooded. The most serious situation occurred at Gerber when a small levee that sets back from the river and near the town gave way. About 500 persons were compelled to vacate their homes temporarily, and the damage there is estimated to be nearly $100,000.

Tehama and Vina being smaller towns, the resultant damage was proportionately less, but a number were driven from their homes, and were cared for by the Red Cross, which agency furnished prompt relief at every point where relief was needed. The flooding in the Vina section was caused by the overflow of Deer Creek near its confluence with the Sacramento.

As heavy flooding of the Gerber-Tehama section occurred near midnight of December 10, and before the main volume of the upstream crest arrived, it is evident that the several creeks with headwaters in the high mountains east and west of the Tehama County section were carrying volumes of water not previously experienced. This was substantiated by the rainfall observer at Beegum on Cottonwood Creek, 43 miles west of Red Bluff, who reported the creek there to have been 1 foot above the previous high-water mark.

A public service storage reservoir on Pine Creek, a tributary of the Pit River in Modoc County, collapsed and flooded much of the town of Alturas, causing property damage and driving many persons from their homes. On the Sacramento River, 3 miles above the mouth of Stony Creek, at Hamilton City, the highest stage was 22.8 feet, or 0.8 foot above the record high stage in 1928. Near the mouth of Stony Creek, the crest was 12.0 feet, at St. John, or 0.6 foot under the record established in 1909. When it is recalled that 8 or 9 feet is an exceptionally high stage for this station, the intensity of the rainfall over the Coast Range can be realized. Of course, the Stony Gorge Reservoir was discharging heavily, having been filled during the November rains.

The Feather River, at Oroville, reached a stage of 26.3 feet, or 1.9 feet below that in 1907, and about equal to the 1928 crest. Water seeping through the porous levee, backed up into the lower section of the city and flooded a number of houses, but at no time was the business section in danger, as the water was 3 or 4 feet below the top of the substantial levee. At Hamilton Bend, about 6 miles below Oroville, the flood water from the Feather River overtopped the west side levee and spread westward over a large area of farming and orchard land in the vicinity of Gridley and Biggs, finally reaching Butte Creek north of the Marysville Buttes. Heavy losses occurred here, as well as in Reclamation Districts No. 10 and 784 in Sutter County on the east side of the river where levees broke, inundating valuable orchard and cultivated lands. Farm houses were submerged to the second stories in the lower parts of these districts.

The peak stage at Marysville, on the Yuba River, was 25.7 feet, or 1.7 feet above the previous highest water of March 1928. A migratory labor camp of the Farm Security Administration, situated on low ground outside the levee, was submerged, and considerable damage resulted to the buildings and grounds, but all the occupants were removed when warnings were issued well in advance.

In the foothills and mountains from the American River northward to Mount Shasta, mountain torrents were unusually destructive to highways, bridges, and railroads in the way of washouts and erosion. The State Division of Highways reports that the total damage to State highway property will exceed half a million dollars; about 20 bridges were destroyed. County roads and bridges also suffered heavy damage. The three principal railroads operating in this district sustained losses aggregating over $300,000. As a result of the storm, railway service was crippled and communication wires and power lines were disrupted. The flooding of the valley floor in many sections, due to numerous breaks in levees and the overflowing of natural banks, seriously interrupted highway traffic and caused widespread damage to agricultural

lands, houses, farm property, and in a few instances, town property.

The 48 gates of the Sacramento Weir were opened about 5 p. m. on the 11th, when the gage at Sacramento was 26.9 feet. Following the opening of the gates, the river fell 0.4 foot and then remained about stationary for 2 hours when it began to rise to a crest of 27.7 feet at 2 a. m. on the 12th.

More than a dozen breaks in the east and west levees occurred in the Butte City-Colusa Weir section, relieving the situation somewhat from Colusa southward. Water pouring through 10 breaks, of increasing width on the west side, caused flooding of large acreage of agricultural lands in Glenn and Colusa counties. Only slight damage occurred from the overflow through the east side levee as the water passed quickly into the Butte Bypass.

The rise at Colusa was considerably checked when widening levee breaks developed above the station. A crest of 26.8 feet occurred prematurely, because the excess flood waters were freely escaping on both sides of the river upstream. However, a slight secondary rise was noted the following day as the accumulation of water in Butte Bypass flowing from the breaks above prevented the full functioning of Colusa and Moulton Weirs.

At Nicolaus, on the lower Feather, a new all-time high stage of 24.6 feet was recorded, 1.4 feet above the previous high in 1928. The Sacramento River at Knights Landing rose steadily from the combined influence of the Feather and the up-Sacramento water, and reached a record high stage of 38.5 feet at Fremont Weir on the 14th, representing a 5-foot overflow along this 2-mile-wide outlet into Yolo Bypass.

Although a 32-foot stage had been forecast for Knights Landing about 2 days in advance, warnings of an extremely dangerous situation were repeated and emphasized as the water rose perilously near the tops of the levees, which were hastily reinforced with bags of sand. A crest of 32.6 feet at Knights Landing on the 14th, established a new absolute high record, 2.6 feet above the flood stage, 0.4 foot above the previous high in 1907, and 1.4 feet above that of March 1928.

In the Yolo Bypass the substandard leveed island tracts of Little Holland, Liberty, and Prospect were submerged, a total area of about 5,000 acres. Two other delta tracts, namely, Upper Hastings and Egbert, narrowly escaped inundation during the extremely high tides on the 14th and 15th. Egbert tract was saved from flooding, it was reported, by the heroic efforts of a crew of several hundred men reinforcing the levees with sand bags. The fact that there was very little wind at the critical time was an important favorable factor.

Unlike most other important floods that have occurred in the central valleys of California, the one under consideration caused no serious situation in the Sacramento-San Joaquin Delta region outside the Yolo Bypass district. This was true because the San Joaquin River was at low stages, the first run-off in its eastern tributaries having gone into the numerous storage reservoirs. The American River also was not as high by about 3 feet as it was in 1907 and 1928; and the early opening of the gates of the Sacramento Weir diverted a large volume of water into the Yolo Bypass, allowing it to escape into the widened channel of the Sacramento River north of Rio Vista. Hence, the city of Sacramento was at no time endangered.

Serious breaks in the levees in the Princeton-Butte City section, north of Colusa allowed the water to spread overland westward and southward in Glenn, Colusa, and Yolo Counties, inundating 100,000 acres of reclaimed land, and extended over an irregular area from Butte City to Knights Landing.

The storm was one of the most intense to occur in this region, considering that in only about 2½ days it produced higher water conditions equaling and exceeding storms of from 6 to 14 days' duration in past years. The bulk of the rain occurred in 48 hours, although some fell over a period of 4 days. The greatest falls occurred in the Feather-Yuba section at elevations between 3,000 and 6,000 feet. In the 2-day period, December 10 and 11, rainfall in excess of 18.00 inches occurred in places. The greatest 24-hour falls reported were 11.61 and 11.48 inches, at Brush Creek, on the Middle Fork of the Feather, and Scales, on the North Fork of the Yuba, respectively. Despite the brevity of the period of downpour, exceptionally high precipitation records were established, as will be seen from the accompanying tabulation.

Rainfall from Dec. 9 to 12, inclusive (inches)

Stations	Elevation	December				Total
		9	10	11	12	
Upper Sacramento	*Feet*					
Squaw Creek	1,130	-------	4.55	5.89	1.57	12.01
Dunsmuir	2,280	T	1.95	5.06	1.62	8.63
Delta	1,138	2.44	5.48	2.08	.01	10.01
Vollmers	1,332	-------	4.30	4.01	.70	9.01
Kennett	655	-------	3.67	7.75	1.03	12.45
Redding	722	2.63	4.85	.66	.01	8.15
Upper Lake	1,343	.72	5.35	3.30	.60	9.97
Feather						
Volta	2,100	.36	1.60	4.05	4.06	10.07
Mineral	4,950	.57	6.88	7.25	.18	14.88
De Sabla	2,700	.75	6.66	5.99	.02	13.42
West Branch	3,216	.73	8.00	7.58	.39	16.70
Las Plumas	569	.87	7.54	4.46	.04	12.91
Quincy	3,409	-------	3.10	5.25	.75	9.10
Brush Creek	3,500	-------	6.35	11.61	.96	18.92
Bucks Creek	1,750	.70	6.47	6.45	.50	14.12
Bucks Storage Reservoir	5,070	.46	(1)	(1)	(1)	19.41
Challenge	2,600	-------	6.12	4.00	6.30	16.42
Yuba-Bear						
Scales	4,300	1.01	11.48	7.37	.67	20.53
Deer Creek	3,700	.30	7.92	4.59	.90	13.71
Colgate	572	.20	2.87	2.90	.22	6.19
Nevada City	2,500	-------	3.95	4.72	1.17	9.84
Bowman Dam	5,347	.26	7.83	5.31	.38	13.78
Spaulding	5,075	.54	8.43	5.20	.60	14.77
American						
Twin Lakes	7,920	.18	3.82	3.78	.84	8.62
Soda Springs	6,752	-------	5.00	5.80	2.03	12.83
Blue Canyon	4,750	.58	5.27	3.28	.65	9.78
Colfax	2,421	-------	3.92	4.62	1.40	9.94
Placerville	1,925	-------	1.95	2.05	1.65	5.65
Forest Hill	3,109	-------	2.14	3.58	1.31	7.03
Georgetown	2,300	-------	3.50	3.10	1.05	7.65

[1] Daily amounts not measured.

Considerable flooding of low sections occurred in Indian Valley on the North Fork of the Feather River in Plumas County. However, little agricultural damage was done, although the homes of about 75 persons were in the affected area.

The heavy discharge of Cache Creek materially intensified the situation in the upper Yolo Basin north of Woodland, where there was overflow damage from this creek. It was also in this vicinity that the escaped water from the 10 levee breaks north of Colusa, spreading southward through the Colusa Trough section, finally reached the Yolo Bypass at Knights Landing Cut, covering, en route, many thousands of acres. Damage to prospective crops was high—grain, rice, and alfalfa lands being eroded. The top soil of some ranches was washed away and deposited on neighboring fields.

Also, it was characteristic in the flood for most of the larger creeks entering the valley laterally to overflow their banks and spread debris and destruction over the adjacent lands. This was notably true of the creeks in Butte, Tehama, and Shasta Counties, the more important ones being Butte, Chico, Deer, Mill, Antelope, and Battle Creeks on the east side, and Cottonwood, Thomas, Stony, Cache, and Putah Creeks on the west side.

Many of these creeks, including those in the Feather-Yuba system developed discharges never before observed, the tremendous flood volumes carrying away bridges and other obstructions. This was exemplified by the damage at Downieville and Alturas and also by the rapid development of flood conditions in Tehama and Butte Counties.

Damage of serious proportions practically halted all surface, dredge, and placer mining throughout northern California in the wake of the destructive stream flow. Dredging operations were hit hardest when flood waters covered machinery, or swept equipment downstream, in almost every tributary of the Sacramento River system. Placer mining areas, notably in Sierra County around Downieville and throughout much of the foothill country, reported widespread damage.

The outstanding characteristic of this flood was the suddenness with which all streams rose to excessive heights simultaneously. This is demonstrated in the character of the debris carried by and left in the wake of the flood on many streams. For instance, at Yuba City, articles of furniture, parts of buildings, and lumber were seen passing down the Feather River. Fowls, hogs, and other farm animals also were carried down on the crest of the flood waters.

The tabulation of losses below is the result of questionnaires returned from authentic sources of information. Judgment was exercised to exclude any overlapping estimates in reports from different officials. For the most part the items were obtained from county and state engineers, county agricultural commissioners, and river observers. Comparisons were also made with other agencies collecting similar statistics.

For the Sacramento drainage area:	
Estimated total damage of all kinds, caused by stream flow [1]	\$7, 127, 950
Estimated value of property saved by warnings	2, 226, 500
Total acreage of agricultural lands flooded	706, 500
Number of persons driven from their homes or places of business	1, 800

[1] Not included are general storm damages, such as from wind, and earth slides and erosion in the mountains. The State of California, Public Works Department, estimates a loss of \$14,635,000, covering all losses from the storm for the entire state.

These total figures are significant in comparison with the statistical data for similar items of losses in past outstanding floods. In the book *Floods in the Sacramento and San Joaquin Watersheds*, by N. R. Taylor, published in 1913, it is stated that the estimated losses due to floods in the Sacramento and San Joaquin Valleys during the floods of 1904, 1907, and 1909, aggregated \$10,325,000, and that the total amount saved during the floods of 1907 and 1909, by reason of the timely warnings that were issued by the Weather Bureau, aggregated close to \$2,000,000.

The total losses in the floods of January and February 1909 were \$2,506,000, while the saving as the result of warnings issued was \$295,000. In the floods of January and February 1911, the values were: \$650,000 and \$230,000, respectively, while in the March 1928 flood they were recorded as \$736,500 and \$200,000, under the respective classification of losses and savings.

In this connection, it must be borne in mind that in the earlier floods the statistics quoted include heavy damage in the San Joaquin Valley also, it being before many of the storage reservoirs were constructed. From all angles of analysis, it is clear that the brief flood of December 1937 in the Sacramento system above the mouth of the American River has no parallel in the flood history of this valley.

Because of the heavy run-off at the sources of the streams in high elevations, augmented somewhat by melting snow over extreme upper limits, all streams were slow to recede. The late November storms deposited about 3 feet of snow over the headwaters of the American River, but at the beginning of the December storm the snow cover above the 6,500-foot level had settled to about 12 inches. During the first day of heavy rainfall, December 10, the old snow melted completely, releasing 2 or 3 inches of additional water.

The popular belief is that devastating floods occur mainly in connection with melting snows, occasioned by heavy rains. The following notations may offer in part an explanation of the occurrence of the recent flood in absence of material snow cover in the mountains.

During a storm period, when a substantial run-off occurs from heavy rains extending to high altitudes, from 2 to 4 feet of snow may completely disappear from a 1,000-foot altitude belt just above the snow line as it was located at the beginning of the rain. This recession of the snow line releases a large volume of snow water over a limited area, but it will not be menacing if it occurs only at rather low or intermediate altitudes. The normally heavy snow cover which prevails at higher levels, under such circumstances, will absorb a great amount of rainfall and thus restrict the run-off over a large proportion of the drainage area constituting the potential flood hazard. If on the other hand, the belt of receding snow extends to comparatively high levels, the area of effective run-off is proportionately increased, due largely to the absence of the snow mantle and its dampening effect on run-off. From this it is apparent that the higher the snow line at the beginning of heavy, general rains, the greater the probability of occurrence of high water.

Several factors have an important bearing on the situation however, such as the intensity and duration of so-called warm rains and the depth and density of the snow cover from intermediate to rather high levels. While it is true that water from melting snow is an important contribution to run-off, its ultimate effect on the flood situation depends upon the width and elevation of the zone over which the snow line recedes during the course of a general rain storm, which determines the magnitude and extent of the effective run-off area.

PRELIMINARY REPORT ON TORNADOES IN THE UNITED STATES DURING 1937

By J. P. KOHLER

[Weather Bureau, Washington, Feb. 3, 1938]

In keeping with the custom inaugurated in the December issue of the REVIEW, 1925, and continued each year thereafter, preliminary statements on loss of life and property damage by tornadoes during the year 1937 are briefly set forth in this article. A final and more detailed study will appear in the *United States Meteorological Yearbook 1937*. The data contained in the latter publication prior to 1935 were printed in the statistical section of the *Report of the Chief of the Weather Bureau*.

Practically all the information given in this summary is abstracted from table 3 SEVERE LOCAL STORMS, contained in the several monthly issues of the REVIEW. The contents of the table of SEVERE LOCAL STORMS have been compiled from the reports of many observers and the various section directors of the Bureau. While it is thought that figures given are substantially correct, it must be remembered that all are subject to change after the final study mentioned above.

While the year 1937 recorded 137 (possibly 150 tornadoes), only 9 less than the 1936 figure (159), fortunately they were far less disastrous. Only 28 deaths were reported in 1937; injured numbered 192 (possibly 195), and property losses in the final study will be in the neighborhood of 3 million dollars. This is a decidedly favorable contrast to the 1936 figures—552 deaths; 2,928 injured, and property losses totalling $26,228,500.

Table 1, TORNADOES AND PROBABLE TORNADOES, shows the monthly frequency and comparative severity during 1937. June, with 44 and possibly 46(table 2), was the month of greatest tornado frequency. May ranks second, with 33 (possibly 36); and April, third, with 18 (possibly 19). Although April's reported number was considerably less than the June totals, vital figures, 14 deaths, 97 injuries, greatly surpassed other monthly corresponding values. Also, April in 1936, with 32 tornadoes, 492 deaths, and 2,539 injured, was the most destructive month. Tornado frequencies for the remaining months of 1937 were as follows: July, 12 (possibly 14); February, 11 (possibly 13); August, 5 (possibly 7); March, 5; October, 4 (possibly 5); September, 4; and possibly 1 in November. No tornadoes or storms bordering on the destructiveness of tornadoes were reported in January or December.

Provided the death figure 28 is not greatly modified by later analysis, it will stand as the lowest tornado mortality total since comparative study was begun in 1916. Previously, 1931, with 36 deaths, was the lowest on record. Also monetary losses will rank close to or below the low 1923 figure of $2,958,750.

Tornadoes occurred during the year in 31 States. Alabama reported 5; Arizona 1, possibly 2 (table 2), Arkansas 4, Colorado 2, Connecticut 1 (possibly 2), Florida 5, Georgia 2, Illinois 1, Indiana 4, Iowa 32 (possibly 3 more), Kansas 19, Kentucky 1, Louisiana 3, Maryland 8, Minnesota 4 (possibly 5), Mississippi 2 (possibly 3), Missouri 8 (possibly 9), Montana 1, Nebraska 5, New Mexico 1, New York 1 (possibly 2), North Carolina 1, North Dakota 1, Oklahoma 6, Oregon 1, Pennsylvania 1, South Carolina 3 (possibly 4), South Dakota 4, Tennessee 2, Texas 5, Wisconsin 3, and there is some possibility that later consideration may include Ohio, Virginia, and West Virginia with 1 tornado each. The large number reported in Iowa and Kansas is due partly to the efficient service covering storms of this type by the Weather Bureau section directors for these respective States. The number of deaths on a State basis was as follows: Alabama 7, Arkansas 3, Iowa 1, Kansas 1, Kentucky 5, Louisiana 5, Minnesota 1, Missouri 3, Oklahoma 1, and Texas 1. Likewise the number injured was: Alabama 32, Arkansas 40, Florida 5, Illinois 2, Iowa 5, Kansas 3, Kentucky 23, Louisiana 8, Minnesota 3, Missouri 47, North Carolina 2, Oklahoma 15, Pennsylvania 2, Tennessee 3, and Texas 2.

Tornado occurrences with regard to frequency and distribution within the month showed a marked degree of grouping or localization in respect to time and area affected. In February, seven tornadoes occurred within 2 days, February 20–21. The first occurred in Missouri; somewhat later in Louisiana and Mississippi on the 20th, and on the 21st Florida and North Carolina reported tornadoes. The five disturbances in March occurred over the period from the 19th to 25th in Louisiana, Alabama, South Carolina, and Kentucky. In early April, on 3 days, tornadoes were reported in Florida and Alabama. Beginning on April 14, and extending through May 5, a series of 18 tornadoes occurred in the Southeastern States, Gulf region, and interior valleys. In the remaining days of May, and during the summer months, June, July, and August, tornadoes occurred frequently in the Southeast and interior States, and occasionally in scattered points in New England, the Northern Rocky Mountains, and Southern Plateau States. They were in general quite closely connected in respect to area and time, while occurrences in September and October were widely scattered.

The most singular destructive tornado action during the year was the result of a series of three tornadoes which swept portions of Green, Christian, Webster, Wright, and Douglas Counties, in the southwestern part of Missouri, on the afternoon of February 20, causing property damage of at least $200,000, and injuries to at least 13 persons, 2 critically, and killed considerable livestock and poultry. The paths of the tornadoes were about 10 miles apart and ran parallel in an almost southwest to northeast direction and were from 1,000 feet to one-fourth mile wide, and from 10 to 30 miles long. A total of 55 homes was damaged or destroyed, together with as many or more barns, garages, and outbuildings. Eyewitnesses reported well-defined, funnel-shaped or twisting clouds in the sections visited by the tornadoes.

If further study shows the storms listed in table 2 on tornadic winds to be true tornadoes, the 1937 number is 150 tornadoes with 28 deaths, 195 injuries, and property losses exceeding $2,924,000 (see tables on following page).

TABLE 1.—*Tornadoes and probable tornadoes*

	January	February	March	April	May	June	July	August	September	October	November	December	Total
Number	0	11	5	18	33	44	12	5	4	4	1	0	137
Deaths reported		0	7	14	3	3	0	1	0	0	0		28
Injuries reported		21	31	97	12	26	0	0	0	5	0		192
Damage [1]		426.3	210.0	318.8	733.3	738.5	23.5	14.5	12.2	332.2	(2)		2,809.3

[1] In thousands of dollars.
[2] Several hundred.

TABLE 2.—*Tornadic winds and possible tornadoes* [1]

	January	February	March	April	May	June	July	August	September	October	November	December	Total
Number	0	2	0	1	3	2	2	2	0	1	0	0	13
Deaths reported		0		0	0	0	0	0		0			0
Injuries reported		0		0	0	(2)	0	1		2			3
Damage [3]		37.2		(4)	8.0	25.0	16.5	8.0		20.0			114.7

[1] Some of these may not be classed as tornadoes in the final study.
[2] Several reported injured.
[3] In thousands ofdollars.
[4] Several hundred.

NORTH ATLANTIC TROPICAL DISTURBANCES OF 1937

By WILLIS E. HURD

[Weather Bureau, Washington, January 1938]

The hurricane season of 1937 was of comparatively short duration. The first tropical disturbance originated on July 29 and the last of definite tropical origin disintegrated over land on October 4. There were nine tropical disturbances in all over the North Atlantic, including the Gulf of Mexico. The final occurrence of the season was the only one on waters of the Caribbean Sea and that over only its extreme northwestern part. The year 1936 was also deficient as to occurrences in the Caribbean.

As in 1936, with 17 disturbances, of which less than 30 percent attained hurricane intensity, the percentage of those of like force, 2 in number, in 1937, was only 22. Thus for 2 consecutive years the percentage of disturbances of full hurricane force was much below the normal of about 50 percent for the past 51 years. The two hurricanes of the year occurred in September. Of the nine disturbances charted, seven occurred wholly or partly in September. Four were charted in the Gulf of Mexico; and the tracks of three, two of which were hurricanes, lay almost entirely in Atlantic waters. Five of the disturbances dissipated over land, one at sea south of Nova Scotia, and three continued toward upper waters of the Atlantic or into the Arctic Ocean.

The only disturbance of the year to cause any considerable amount of damage was that of August 24–September 2 (track III in the chart). The damage occurred partly as the result of wind and rain in northern Florida on August 30, but was largely due to the heavy rains of the disturbance with accompanying floods over southern Alabama on August 31–September 1. A disturbance was in progress in the Gulf of Mexico from November 23 to 26, but it was apparently of extratropical origin. This disturbance was discussed in the November issue of the REVIEW.

A synopsis of some of the more important features of the nine disturbances of 1937 is given in the table herewith. Their tracks, numbered I to IX chronologically, are shown in the accompanying chart.

North Atlantic tropical disturbances of 1937

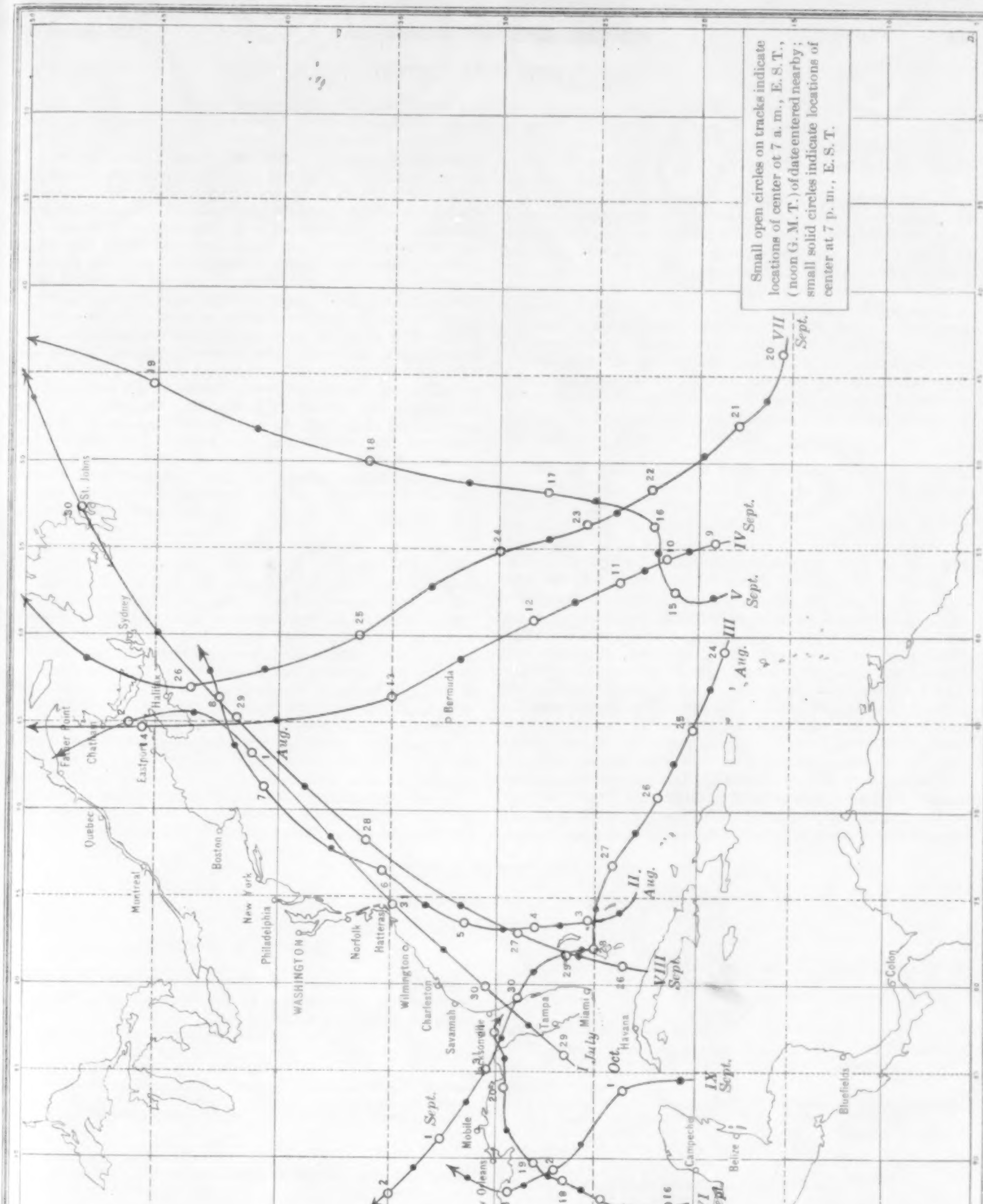
[Synopsis of tropical disturbances of 1937 (number of storm in table corresponds to number of track on accompanying chart)]

Storm	Date	Place where first reported	Coast lines crossed	Maximum wind velocity reported	Lowest barometer reported	Place of dissipation	Intensity	Remarks
I	July 29–Aug. 2	Off west coast of Florida.	Florida, Nova Scotia.	60 miles, SW. S. S. *Mundixie*. Force 10, S. S. *Clare*.	29.44, S. S. *Clare*	St. Lawrence Valley.	Not of hurricane force.	Small damage to fruit and roads in Florida (A).
II	Aug. 2–8	Near 24° N., 76° W.	None	Force 10, on 3 vessels	29.67, S. S. *American Trader*.	Near Sable Island.	do	No damage reported (B).
III	Aug. 24–Sept. 2	Northeast of Leeward Islands.	Florida	Force 10, S. S. *Solana*	29.38, Coast Guard, Daytona Beach, Fla.	Arkansas	do	Some damage due to wind, rain, and floods (B).
IV	Sept. 9–14 [1]	Near 18° N., 55° W.	Nova Scotia, Maine.	Force 10, S. S. *Winamac* and S. S. *Darcoila*.	29.30, on 3 vessels	St. Lawrence Valley.	do	(C).
V	Sept. 14–19 [2]	Northeast of Leeward Islands.	None	Force 12, several vessels.	28.20, on M. S. *California Express*.	North Atlantic	Hurricane	(C).
VI	Sept. 16–21	Gulf of Campeche	Florida	Force 10, S. S. *Oliver Olson*.	29.64, Port Eads, La.	Florida	Not of hurricane force.	(C).
VII	Sept. 20–26	Near 15° N., 44° W.	Nova Scotia, Newfoundland.	Force 12, S. S. *Nordenham*.	28.94	Arctic Ocean	Hurricane	(C).
VIII	Sept. 26–30	Near north coast of Cuba.	Newfoundland	Force 8, S. S. *Gulfhawk*.	29.83	North Atlantic	Not of hurricane force.	(C).
IX	Sept. 30–Oct. 4.[3]	South of Yucatan Channel.	Louisiana	Force 8, S. S. *Gulfprince*.	29.62	Arkansas	do	(C).

Complete reports of these disturbances may be found in the MONTHLY WEATHER REVIEW: (A) July 1937; 65: 281, 282. (B) August 1937; 65: 303, 304. (C) September 1937; 65: 332-335.

[1] Disturbed conditions were reported in the vicinity as early as the 6th, but no evidences until the 9th of a storm center.
[2] On Sept. 10 the S. S. *Chincha*, near 19½° N., 40° W., reported a fresh to strong east-southeast gale and signs of a tropical cyclone.
[3] This disturbance was associated with a second LOW on Oct. 1. The 2 apparently merged on Oct. 2.

Paths of Hurricanes and Other Tropical Storms, 1937
(Plotted by W. E. Hurd)



NOTES AND REVIEWS

Ch. Maurain. *Étude pratique des Rayonnements solaire, atmosphérique et terrestre.* Paris; Gauthier-Villars, 1937.

This volume, of nearly 200 pages, contains an extended discussion of instruments and methods for measuring the duration of sunshine, the intensity of direct solar radiation, the intensity of total solar and sky radiation, and the amount of terrestrial radiation, accompanied by a number of photographic illustrations of the instruments. Attention is also given to the reflectivity of the earth's surface, observations of ultra-violet radiation, and to the luminous equivalent of solar and sky radiation. Tabular summaries of representative data from various stations are included.

In addition, the determination of the solar constant is described, and the physical processes of the depletion of solar radiation while traversing the atmosphere are discussed; spectral intensity distributions of the different types of radiations, atmospheric turbidity, the theoretical calculation of the distribution of insolation beyond the outer limits of the appreciable atmosphere, and the theoretical calculation of the outgoing terrestrial radiation are also treated, together with the general radiation balance in the atmospheric system and its significance for climate.—*Edgar W. Woolard.*

Thomas A. Blair. *Weather Elements: A Text in Elementary Meteorology.* New York; Prentice-Hall, 1937.

This book, by a member of the United States Weather Bureau who conducts instruction in meteorology at the University of Nebraska, is designed to be an introductory college textbook of elementary meteorology. An introductory chapter gives a general description of the scope of meteorology, and of the nature and general properties of the atmosphere and of the elements involved in weather and climate. The next two chapters describe the instruments and procedures for observing temperature, pressure, wind, and other meteorological elements, together with methods for obtaining data from the upper air. The following chapters discuss solar radiation and its effects, lapse rates and stability in the atmosphere, and the general structure of the atmosphere. Phenomena resulting from the condensation of water vapor in the atmosphere are discussed in chapter 5; pressure gradients, winds, the general circulation of the atmosphere, and cyclones and anticyclones are treated in the next three chapters, followed by a chapter on thunderstorms, tornadoes, waterspouts, chinooks, etc.

Chapter 10 is devoted to weather forecasting, including a brief treatment of air mass analysis. The subject of world weather, including tele-connections, climatic fluctuations, influence of ocean currents, etc., is discussed in chapter 11. A brief treatment of the climates of the world and of the United States, and of climatic trends and controls, is given in chapter 12; while the next chapter is devoted to agricultural and aeronautical meteorology, and to the effects of climate on health and civilization.

The concluding chapters contain a treatment of electrical and optical phenomena, and an account of the work of the United States Weather Bureau. A list of books for further reading and several miscellaneous tables complete the volume.—*Edgar W. Woolard.*

Monthly Broadcasts of Climatological Data for North America.—The International Meteorological Organization, of which the United States Weather Bureau is a member, adopted at its meeting held in Warsaw, Poland, during September 1935 a resolution asking that climatological data from representative meteorological stations on each continent be broadcast by radio monthly for the use of other meteorological services as an aid in the study of world weather and long range weather forecasting. The United States Weather Bureau inaugurated in March 1937 monthly broadcasts of climatological data from selected stations in North America through the United States Navy Radio Station NAA/NSS, Washington, D. C.

These broadcasts are made on the 5th of each month but the data contained in the messages are for the preceding month. Mean monthly values of barometric pressure and temperature and total precipitation for 21 stations in the continental United States, 26 in Canada and Newfoundland, 2 stations in Alaska, and 1 each in Puerto Rico and Hawaii are included in each broadcast. The data are sent in a figure code which is easily translatable.

BIBLIOGRAPHY

[Richmond T. Zoch, *in Charge of Library*]

By Amy D. Putnam

RECENT ADDITIONS

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SOLAR OBSERVATIONS

SOLAR RADIATION MEASUREMENTS DURING DECEMBER 1937

By IRVING F. HAND

For a description of instruments employed and their exposures, the reader is referred to this REVIEW, page 418.

Table 1 shows that solar radiation intensities averaged above normal for the month at Washington and Lincoln, and close to normal at Madison and Blue Hill.

Table 2 shows an excess in the amount of total solar and sky radiation received on a horizontal surface during December at all stations with the exception of Twin Falls, Miami, Riverside, Blue Hill, Ithaca, and Friday Harbor. The percentage departures for the year show that all stations had an excess of radiation with the exception of Twin Falls, Miami, Riverside, San Juan, Ithaca, and Friday Harbor.

No polarization observations were made during December at Madison owing to continual snow and ice cover.

TABLE 1.—*Solar radiation intensities during December 1937*

[Gram-calories per minute per square centimeter of normal surface]

WASHINGTON, D. C.

Date	Sun's zenith distance										
	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass: A. M.					P. M.				Local mean solar time
	e	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	e
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
Dec. 1	3.00	0.61	0.70	0.81	1.08						2.62
Dec. 3	2.26	.92	1.03	1.18							2.26
Dec. 8	2.13				1.25						2.06
Dec. 9	1.32	.86	.95	1.14	1.34			1.07	0.82		1.60
Dec. 10	1.96	.92	1.05	1.19	1.37						1.19
Dec. 11	1.78	.72	.84	1.11							1.37
Dec. 14	1.45				1.31			1.04			1.52
Dec. 24	2.87	.74	.95	1.10							3.30
Dec. 29	3.63							1.05			3.30
Means		.80	.92	1.09	1.27			1.05	(.82)		
Departures		+.01	+.02	+.04	+.04			+.01	−.09		

TABLE 1.—*Solar radiation intensities during December 1937*—Con.

[Gram-calories per minute per square centimeter of normal surface]

MADISON, WIS.

Date	Sun's zenith distance										
	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass A. M.					Air mass P. M.				Local mean solar time
	e	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	e
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
Dec. 2	2.26	0.92	1.05	1.18							2.74
Dec. 10	.86		1.12	1.14							1.47
Means		(.92)	(1.09)	(1.16)							
Departures		−.04	+.01	−.05							

LINCOLN, NEBR.

Date	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
Dec. 1	2.74	1.00	1.08	1.27	1.48			1.27	1.16		2.74
Dec. 2	3.63	.81	.93	1.09							4.57
Dec. 5	1.02	1.17	1.28	1.41				1.37	1.22	1.09	.74
Dec. 6	.86	1.07		1.23							.81
Dec. 7	2.49			1.15							.96
Dec. 8	.71	1.03	1.06							1.00	.79
Dec. 9	.79	1.17	1.24	1.35				1.33	1.22	1.10	.71
Dec. 10	.79	1.10	1.25	1.39				1.31	1.14	1.01	.74
Dec. 15	3.15							1.10	.99	.91	3.81
Dec. 16	2.62							1.29	1.18	1.09	5.36
Dec. 20	2.36								1.02	.96	2.16
Dec. 21	2.62		1.08	1.23				1.24	1.08	.94	3.63
Dec. 22	2.74	1.04	1.16	1.29							2.87
Dec. 25	1.88		1.18								2.62

TABLE 1.—*Solar radiation intensities during December 1937*—Con.

[Gram-calories per minute per square centimeter of normal surface]

LINCOLN, NEBR.—Continued

Date	Sun's zenith distance										
	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass A. M.					Air mass P. M.				Local mean solar time
	e	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	e
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
Dec. 27	3.45	0.97	1.08	1.25					1.06	0.91	4.17
Dec. 29	3.15							1.27			3.81
Dec. 31	3.91	1.41	1.24	1.35				.96	.80	.67	1.96
Means		1.05	1.14	1.27	(1.48)			1.24	1.09	.97	
Departures		+.09	+.04	+.04	+.09			+.04	+.02	+.01	

BLUE HILL, MASS.

Date	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
Dec. 10	2.1						1.37	1.19	1.04	0.92	1.7
Dec. 11	1.9	0.85	0.98	1.10	1.22		1.24	1.05			1.8
Dec. 12	1.6	.68	.85	.95	1.12		1.24	1.05			1.8
Dec. 13	1.8	.68	.80	1.00	1.30		1.20	.95			1.3
Dec. 14	1.1	1.05	1.19	1.30	1.42		1.40	1.21	1.02	.83	1.5
Dec. 15	1.6						1.24	1.11	.96		2.2
Dec. 19	3.8						1.20	1.18	1.09	.99	4.0
Dec. 27	2.0	.83	1.02	1.21	1.40		1.38	1.27	1.19		1.9
Dec. 29	2.0						1.43	1.29			1.6
Means		.82	.97	1.11	1.29		1.31	1.14	1.06	.91	
Departures		−.08	−.07	−.12	−.10		0	+.04	+.02	−.04	

*Extrapolated.

TABLE 2.—*Average daily totals of solar radiation (direct+diffuse) received on a horizontal surface*

Week beginning—	Washington	Madison	Lincoln	Chicago	New York	Fresno	Fairbanks	Twin Falls	La Jolla	Miami	New Orleans	Riverside	Blue Hill	San Juan	Friday Harbor	Ithaca	Newport
	Gram-calories per square centimeter																
	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.
Dec. 3	165	120	207	85	125	206	12	152	231	300	168	218	140	394	94	118	118
Dec. 10	158	74	129	61	145	145	8	62	242	287	190	189	174	424	63	112	166
Dec. 17	131	103	142	71	109	160	6	131	262	246	200	241	132	435	86	59	131
Dec. 24 [1]	143	86	173	66	91	171	13	131	230	273	192	232	131	432	55	76	130
	Departures from weekly normals																
Dec. 3	+6	+3	+33	+15	+21	+14	+4	+37		+4	−17	+13	+4		+6	+28	
Dec. 10	+21	−38	−35	−17	+41	−31	+3	−52		−18	+24	−7	+43		−9	+25	
Dec. 17	−13	−16	−35	−16	+11	+10	0	+13		−30	−24	−8	−7		+15	−28	
Dec. 24 [1]	−6	−35	−1	−18	−23	+29	+7	−2		−9	+40	+32	0		−16	−18	
	Accumulated departures on Dec. 31																
	+182	+8,913	+5,173	+6,559	+6,930	+8,568	+2,940	−1,904		−9,114	+5,341	−4,361	−2,891		−2,030	−6,720	
	Percentage departures for year																
	+.1	+7.5	+3.8	+6.6	+6.7	+5.1	+3.7	−1.3		−6.1	+4.3	−3.8	−1.3		−1.8	−6.3	

[1] 8-day mean.

POSITIONS AND AREAS OF SUN SPOTS

[Communicated by Capt. J. F. Hellweg, U. S. Navy (Ret.), Superintendent, U. S. Naval Observatory. Data furnished by the U. S. Naval Observatory in cooperation with Harvard and Mount Wilson Observatories. The difference in longitude is measured from the central meridian, positive west. The north latitude is positive. Areas are corrected for foreshortening and are expressed in millionths of the sun's visible hemisphere. The total area for each day includes spots and groups]

Date	Eastern standard time	Mt. Wilson group number	Heliographic: Diff. in longitude	Heliographic: Longitude	Heliographic: Latitude	Area: Spot	Area: Group	Total area for each day	Observatory
1937	h. m.		°	°	°				
Dec. 1	11 25	5664	−36.0	98.0	−10.0		24	24	U. S. Naval.
Dec. 2	11 52	5670	−70.0	50.6	−20.0	48			Do.
		5669	−49.5	71.1	−18.5	48			
		5664	−22.0	98.6	−10.0	6			
		5663	−15.0	105.6	+10.0		12		
		5668	−12.0	108.6	−13.0		36		
		5667	+53.0	173.6	+29.5		24	174	
Dec. 3	11 5	5671	−70.0	37.9	+12.0	12			Do.
		5670	−58.0	49.9	−19.0	61			
		5664	−10.0	97.9	−9.5		12	85	
Dec. 4	11 32	5671	−57.0	37.4	+13.0	12			Mt. Wilson.
		5670	−48.0	46.4	−19.0		61		
		5664	+3.0	97.4	−9.0		12	85	
Dec. 5	11 12	5676	−79.0	2.4	+22.0	48			Do.
		5675	−53.5	27.9	+8.0	16			
		5670	−35.5	45.9	−19.0		61		
		5674	+18.0	99.4	−17.0		73		
		5673	+66.0	147.4	−23.0		36	234	
Dec. 6	11 11	5676	−66.0	2.3	+23.0	61			Do.
		5670	−18.0	50.3	−18.0	36			
		5678	−13.0	55.3	−26.0		85		
		5677	+1.0	69.3	−18.5		24		
		5672	+31.0	99.3	+12.0		24		
		5674	+32.0	100.3	−17.0		242		
		5673	+80.0	148.3	−25.0	24		496	
Dec. 7	11 7	5676	−52.0	3.1	+22.0		36		U. S. Naval.
		5670	−5.0	50.1	−19.0	16			
		5678	+1.0	56.1	−25.5		36		
		5677	+16.0	71.1	−19.0		36		
		5674	+45.0	100.1	−18.0		291		
		5672	+45.0	100.1	+11.0		24	439	
Dec. 8	11 9	5676	−40.0	1.9	+21.5	16			Do.
		5670	+9.0	50.9	−19.0	16			
		5678	+13.0	54.9	−25.0	12			
		5679	+30.5	72.4	−19.0	24			
		5674	+59.0	100.9	−18.5		194		
		5672	+59.0	100.9	+11.0		48	310	
Dec. 9	11 17	5682	−74.0	314.7	+8.0	73			Do.
		5683	−74.0	314.7	−22.0		145		
		5676	−27.0	1.7	+22.0	36			
		5670	+22.0	50.7	−18.0	16			
		5679	+44.0	72.7	−18.0	16			
		5672	+72.0	100.7	+11.0		97		
		5674	+72.0	100.7	−18.0		194	577	
Dec. 10	10 58	5683	−62.0	313.7	−22.0		485		Do.
		5682	−59.0	316.7	+8.0		97		
		5676	−13.0	2.7	+22.0	24		606	
Dec. 11	11 2	5683	−50.0	312.5	−21.0		970		Do.
		5682	−44.0	318.5	+9.0		145		
		5681	−24.0	338.5	−23.0		97	1,212	
Dec. 12	13 32	5683	−35.0	312.9	−21.0		921		Do.
		5682	−29.0	318.9	+9.0		339		
		5681	−10.0	337.9	−23.0		97		
		5680	+7.0	354.9	−22.0		97	1,454	
Dec. 13	11 9	5683	−24.0	312.0	−20.0		921		Mt. Wilson.
		5682	−14.0	322.0	+10.0		485		
		5681	+4.0	340.0	−22.0		97		
		5680	+19.0	355.0	−21.0		97		
		5684	+33.0	9.0	+13.0		121	1,721	
Dec. 14	12 15	5688	−83.0	239.3	+26.0	727			U. S. Naval.
		5685	−19.0	303.3	−6.0		73		
		5683	−10.0	312.3	−20.0		824		
		5682	0.0	322.3	+9.0		533		
		5681	+18.5	340.8	−22.0	36			
		5687	+19.0	341.3	−9.5		61		
		5680	+30.0	352.3	−22.0	36			
		5686	+40.0	2.3	+23.0		85		
		5684	+47.0	9.3	+14.0		121	2,496	
Dec. 15	14 46	5688	−70.0	237.7	+27.0		1,454		Mt. Wilson.
		5692	−65.0	242.7	−23.0	48			
		5685	−3.0	304.7	−6.0		194		
		5683	+5.0	312.7	−20.0		679		
		5691	+5.0	312.7	+10.0		48		
		5690	+15.0	322.7	−9.5		36		
		5689	+30.5	338.2	+5.0		48		
		5687	+34.0	341.7	−10.0		48		
		5686	+55.0	2.7	+23.0		194		
		5684	+62.0	9.7	+14.0		48	2,797	

POSITIONS AND AREAS OF SUN SPOTS—Continued

Date	Eastern standard time	Mt. Wilson group number	Heliographic: Diff. in longitude	Heliographic: Longitude	Heliographic: Latitude	Area: Spot	Area: Group	Total area for each day	Observatory
1937	h. m.		°	°	°				
Dec. 16	14 27	5688	−57.0	237.7	+27.0		1,115		U. S. Naval.
		5692	−55.0	239.7	−22.0		48		
		5693	−43.0	251.7	+23.0		48		
		5685	+10.0	304.7	−6.0		48		
		5691	+18.0	312.7	+9.0		61		
		5683	+19.0	313.7	−20.0		582		
		5682	+27.0	321.7	+9.0		485		
		5687	+50.0	344.7	−11.0		12		
		5686	+67.0	1.7	+23.0		194		
		5684	+70.0	4.7	+14.0	12		2,605	
Dec. 17	11 26	5688	−45.0	238.2	+27.0		1,115		Mt. Wilson.
		5692	−38.0	245.2	−20.0		24		
		5693	−30.0	253.2	+24.0		97		
		5685	+22.0	305.2	−6.0		48		
		5691	+25.5	308.7	+10.0		121		
		5683	+32.0	315.2	−20.0		533		
		5682	+39.0	322.2	+10.0		485		
		5687	+60.0	343.2	−9.0		36	2,459	
Dec. 18	10 51	5688	−33.0	237.4	+27.0		873		U. S. Naval.
		5692	−28.0	242.4	−21.0		194		
		5693	−17.0	253.4	+23.0		36		
		5685	+36.0	306.4	−7.0		36		
		5691	+43.0	313.4	+9.0		97		
		5683	+44.0	314.4	−21.0		388		
		5682	+54.0	324.4	+8.0		291	1,915	
Dec. 19	12 54	5688	−17.0	239.0	+27.0		679		Do.
		5692	−12.0	244.0	−21.5	24			
		5693	−3.0	253.0	+22.0		388		
		5691	+57.0	313.0	+9.0		97		
		5683	+58.0	314.0	−21.0		400		
		5682	+68.0	324.0	+8.0		242	1,830	
Dec. 20	11 20	5696	−69.0	174.7	−26.5	36			Do.
		5688	−5.0	238.7	+27.0		582		
		5693	+10.0	253.7	+22.0		194		
		5691	+69.0	312.7	+9.0		97		
		5683	+70.0	313.7	−21.0		339	1,248	
Dec. 21	11 6	5696	−57.0	173.7	−27.0	48			Do.
		5688	+2.0	232.7	+28.0	36			
		5688	+9.0	239.7	+27.0		582		
		5693	+23.0	253.7	+22.0		194		
		5691	+82.0	312.7	+10.0		291		
		5683	+83.0	313.7	−20.5		242	1,393	
Dec. 22	11 12	5699	−72.0	145.5	−9.0	242			Do.
		5698	−67.0	150.5	−5.0	12			
		5697	−47.0	170.5	−8.0		12		
		5696	−43.0	174.5	−27.5	48			
		5695	−40.0	177.5	+10.0		24		
		5688	+23.0	240.5	+27.0		582		
		5693	+40.0	257.5	+21.0		145	1,065	
Dec. 24	10 59	5699	−47.0	144.2	−11.0		485		Mt. Wilson.
		5702	−40.0	151.2	+10.0		97		
		5703	−40.0	151.2	+21.0		24		
		5701	−30.0	161.2	−9.5	24			
		5696	−18.0	173.2	−27.0	36			
		5695	−11.0	180.2	+9.0		242		
		5688	+51.0	242.2	+27.0		533		
		5693	+68.0	259.2	+22.0		145	1,586	
Dec. 25	11 37	5704	−73.0	104.7	+13.0	218			U. S. Naval.
		5699	−33.0	144.7	−11.0		436		
		5703	−28.0	149.7	−20.0		97		
		5702	−26.0	151.7	+10.5		97		
		5698	−25.0	152.7	−4.5		12		
		5695	+3.0	180.7	+10.0		242		
		5688	+64.0	241.7	+27.0		436		
		5693	+83.0	260.7	+21.0		48	1,586	
Dec. 26	12 23	5704	−59.0	105.1	+13.0		218		Do.
		5699	−18.0	146.1	−11.0		388		
		5703	−13.0	151.1	−20.0		291		
		5702	−12.0	152.1	+10.0		97		
		5695	+17.0	181.1	+9.5		194		
		5688	+77.0	241.1	+27.0		388	1,576	
Dec. 27	14 38	5704	−44.0	105.7	+12.0		145		Mt. Wilson.
		5706	−12.0	137.7	−9.0		16		
		5699	−4.0	145.7	−11.0		388		
		5703	+1.0	150.7	−20.0		727		
		5702	+4.0	153.7	+10.0		145		
		5695	+32.0	181.7	+9.5		291		
		5705	+55.0	204.7	−7.0		97	1,809	
Dec. 28	11 23	5704	−31.0	107.3	+12.0		145		U. S. Naval.
		5708	−30.5	107.8	+17.5	6			
		5699	+9.0	147.3	−11.0		339		
		5703	+13.0	151.3	−20.0		727		
		5702	+17.0	155.3	+10.5		97		
		5695	+44.0	182.3	+9.5		436		
		5705	+63.0	201.3	−6.0	48		1,798	

POSITIONS AND AREAS OF SUN SPOTS—Continued

Date	Eastern standard time	Mt. Wilson group number	Heliographic: Diff. in longitude	Heliographic: Longitude	Heliographic: Latitude	Area: Spot	Area: Group	Total area for each day	Observatory
1937	h. m.		°	°	°				
Dec. 29	11 55	5712	−32.0	92.9	−16.0	...	48	...	Do.
		5704	−19.0	105.9	+12.5	...	194	...	
		5707	−9.0	115.9	+19.0	...	24	...	
		5711	−9.0	115.9	+14.5	...	12	...	
		5710	+8.0	132.9	−14.5	...	36	...	
		5699	+23.0	147.9	−11.0	...	242	...	
		5703	+26.0	150.9	−20.0	...	582	...	
		5702	+30.0	154.9	+10.0	...	36	...	
		5695	+59.0	183.9	+10.0	...	194	1,368	
Dec. 30	12 12	5712	−19.0	92.5	−15.0	...	97	...	Mt. Wilson.
		5704	−6.0	105.5	+13.0	...	194	...	
		5707	+7.5	119.0	+19.0	...	24	...	
		5710	+22.0	133.5	−14.5	36	...	...	
		5709	+26.0	137.5	−16.0	...	24	...	
		5699	+36.0	147.5	−11.0	...	242	...	
		5703	+39.0	150.5	−21.0	...	485	...	
		5702	+45.0	156.5	+10.0	...	36	...	
		5695	+70.0	181.5	+9.0	...	97	1,235	
Dec. 31	11 20	5713	−75.0	23.8	+5.0	...	388	...	U. S. Naval.
		5712	−7.0	91.8	−15.0	...	145	...	
		5704	+9.0	107.8	+12.5	...	97	...	
		5707	+20.0	118.8	+19.5	...	73	...	
		5710	+37.0	135.8	−14.5	24	...	...	
		5709	+40.0	138.8	−15.0	...	48	...	
		5699	+50.0	148.8	−11.0	...	242	...	
		5703	+53.0	151.8	−20.0	...	339	...	
		5702	+58.0	156.8	+11.0	24	...	1,380	

Mean daily area for 30 days=1,252.

PROVISIONAL SUNSPOT RELATIVE NUMBERS, DECEMBER 1937

[Dependent alone on observations at Zurich and its station at Arosa]

[Furnished through the courtesy of Prof. W. Brunner, Eidgen. Stern-Warte, Zurich, Switzerland]

December 1937	Relative numbers	December 1937	Relative numbers	December 1937	Relative numbers
1	14	11	*Ec* 72	21	86
2	*Wc* 33	12	70	22	*Ecd* 90
3	...	13	*Mc* 107	23	*Ec* 107
4	...	14	*Macd* 112	24	...
5	55	15	*Wac* 141	25	*a*
6	...	16	*Ec* 155	26	...
7	...	17	...	27	*aa* 125
8	...	18	109	28	*a* 103
9	...	19	*a* 124	29	*Mc* 113
10	56	20	*b* 107	30	*Mc* 111
				31	*ad* 112

Mean, 21 days=95.3

a=Passage of an average-sized group through the central meridian.
b=Passage of a large group or spot through the central meridian.
c=New formation of a group developing into a middle sized or large center of activity; *E*: on the eastern part of the sun's disc; *W*: on the western part; *M*: in the central circle zone.
d=Entrance of a large or average-sized center of activity on the east limb.

AEROLOGICAL OBSERVATIONS

[Aerological Division, D. M. LITTLE in Charge]

By LOYD A. STEVENS

Mean free-air data, based on airplane weather observations during December 1937, are given in tables 1 to 3. A description of the methods by which the various monthly means and normals therein are computed may be found in the aerological sections of the MONTHLY WEATHER REVIEW for January and March 1937.

It will be noted that many of the "normals" are based on only 3 years of observations. Conclusions based on departures from such short period "normals" must be used with caution.

The mean surface temperatures for December (see chart I) were, in general, above normal over the Rocky Mountain and Pacific coast regions and over portions of the North Atlantic and southern New England States; elsewhere they were below normal. The greatest positive departures (+3° C. to +4° C.) occurred over portions of the Rocky Mountains while the greatest negative departures (−1° C. to −2° C.) occurred over a region whose center was approximately over the state of Illinois.

With a few exceptions, the mean free-air temperatures for the month, up to 5 kilometers, were below normal. The most significant exception occurred over Oakland, Calif., where the temperature was above normal at all levels, the greatest positive departure from normal (+1.5° C.) occurring at 0.5 and 1 kilometer. The greatest negative departures at all levels occurred over the region of the Great Lakes (−4.3° C. at Sault Ste. Marie at 1.5 km) with a secondary center of large negative departures over Spokane, Wash. (−3.0° C. at 4 and 5 km) in the higher levels. The highest mean temperatures occurred over San Diego up to 2 kilometers and over Pensacola above 2 kilometers. The lowest mean temperatures occurred over Fargo at 0.5 kilometer and over Sault Ste. Marie at all other levels. The mean free-air temperatures for December were lower than for November by 4° C. to 8° C. over the northern part of the country. This difference in temperature between the 2 months decreased toward the south, however, and amounted to only 1° to 3° C. over the southern part of the country. The greatest decrease in the mean temperature occurred over Fargo at 0.5 kilometer where the value for December (−12.3° C.) was 9.1° C. lower than that for November (−3.2° C.).

The mean free-air relative humidities, shown in table 2, were above normal over most of the country at all levels. Minus departures were confined largely to the Northeastern States in the lower levels and to Pensacola at all except the 0.5 kilometer level. The greatest positive departure (+14 percent) occurred over San Diego at 3 kilometers while the greatest negative departure (−11 percent) occurred over Pensacola at both 3 and 5 kilometers.

The mean free-air barometric pressures are shown in table 3. In general there was a decrease in the average pressures for December as compared with those for November except that in the lower levels there were small increases of 1 to 2 millibars at most stations. The mean free-air isobaric charts, as drawn from the values in table 3, were characterized by well-defined statistical centers of low pressure over the region of the Great Lakes; the lowest mean pressures for the entire country occurring at Sault Ste. Marie, Mich., at all levels. The highest mean pressures occurred over Pensacola, Fla., at all levels. Over the eastern part of the country there was a pronounced steepening of the south to north pressure gradient in December as compared with November but a slight decrease in gradient occurred over the western part of the country.

Free-air resultant winds, based on pilot-balloon observations made near 5 a. m. (75th meridian time), are shown in table 4. In general the resultant directions were re-

markably close to the normal at nearly all stations and at all levels. The most outstanding exceptions occurred at San Diego where the current directions at 0.5 and 1 kilometer were E. (93°) and ESE. (123°), respectively, while the corresponding normal directions are N. (2°) and NNW. (344°). Resultant velocities were for the most part, near normal. The greatest positive departure from normal (+6.0 m. p. s.) occurred over Nashville at 2.5 kilometers and the greatest negative departure (−3.9 m. p. s.) occurred over San Diego at 5 kilometers.

Table 5 shows the maximum free-air wind velocities and their directions for various sections of the United States during December as determined by pilot-balloon observations. The extreme maximum for the month was 80.4 meters per second from the northeast at an altitude of 5,520 meters above sea level over Las Vegas, Nev.

The mean monthly specific humidities and equivalent potential temperatures for the month are shown in tables 2 and 3, respectively. There was a decrease in the average specific humidities of December as compared with November over the greater portion of the country in the lower levels. In the upper levels, however, most of the southern stations showed either no change or slight increases. The greatest decrease (−1.8 grams) occurred over Maxwell Field at 0.5 kilometer and the greatest increase (+0.7 gram) occurred over San Diego at 3 kilometers. The mean equivalent potential temperatures for December were lower than for November by amounts ranging from 2° A. over San Diego to 13° A. over Fargo at 0.5 kilometer and ranging between 1° A. over San Diego to 6° A. over Sault Ste. Marie at 5 kilometers. The lowest mean specific humidities and equivalent potential temperatures occurred over Fargo in the lower levels and over Sault Ste. Marie in the upper levels. The highest mean specific humidities occurred over San Diego at all levels up to 4 kilometers. The highest equivalent potential temperatures likewise occurred over San Diego up to 3 kilometers and over Pensacola at 4 and 5 kilometers.

The weather for the month over the eastern part of the country was dominated largely by the frequent passage of rather cold and dry Pp air masses and by relatively few invasions of Ta air. Consequently both the mean temperature and average precipitation were below normal over that area. Over the western part of the country the weather was influenced greatly by the development of large and unusually deep low pressure areas over the north Pacific Ocean during two different periods of the month; the circulation about these LOWS brought in great quantities of warm moist Tp air over the Pacific coast and Rocky Mountain regions. This accounted largely for the high average temperatures and excess precipitation which occurred over that part of the country during the month.

TABLE 1.—*Mean free-air temperatures (t), °C. obtained by airplanes during December 1937. ("Dep." represents departure from "normal" temperature)*

Stations	Number of obs.	Altitude (meters) m. s. l.																	
		Surface		500		1,000		1,500		2,000		2,500		3,000		4,000		5,000	
		t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.
Barksdale Field [1] (Shreveport), La. (52 m)	19	5.4		5.5		4.8		3.6		2.2		0.0		−1.4		−6.7			
Billings, Mont.[2] (1,090 m)	31	−3.3	−0.3					−0.4	−0.5	−2.2	−0.8	−5.1	−0.9	−8.2	−0.7	−14.5	−0.7	−21.0	−0.6
Boston, Mass.[1] (5 m)	22	−2.7	−0.6	−4.6	−1.7	−5.8	−1.6	−6.6	−1.5	−7.3	−1.1	−8.5	−0.5	−10.3	−0.1	−15.5	−0.3		
Cheyenne, Wyo.[2] (1,873 m)	31	−3.5	+0.1							−2.1	−0.2	−2.7	−0.8	−4.7	−0.2	−10.7	−0.3	−17.5	−0.3
Chicago, Ill.[2] (187 m)	20	−4.3	−2.2	−5.0	−3.0	−5.1	−2.8	−5.1	−2.5	−6.3	−2.7	−7.7	−2.7	−9.7	−2.4	−13.7	−1.4	−19.3	−0.8
Coco Solo, Canal Zone.[3] (15 m)	19	24.6		22.9		20.4		17.7		15.1		12.9		10.5		4.6		−1.5	
El Paso, Tex.[2] (1,194 m)	31	4.4	+0.6					6.7	+0.1	4.6	−0.8	2.6	−0.6	0.5	−0.5	−4.8	−0.4	−11.4	−0.7
Fargo, N. Dak.[2] (274 m)	31	−13.9	−1.5	−12.3	−1.1	−9.2	−0.4	−8.7	−1.2	−9.3	−1.1	−10.8	−0.8	−12.9	−0.7	−18.0	−0.4	−23.7	+0.1
Kelly Field (San Antonio), Tex.[1] (206 m)	8	9.7		9.7		8.1		6.8		5.6		3.3		1.8		−3.6		−10.4	
Lakehurst, N. J.[3] (39 m)	22	−1.3	+0.3	−1.5	0.0	−3.1	0.0	−3.9	0.0	−6.1	−0.7	−7.9	−0.3	−10.5	−0.7	−16.7	−1.5	−20.4	+0.4
Maxwell Field (Montgomery), Ala.[1] (52 m)	28	6.9	+1.6	6.9	+0.1	5.9	−0.3	5.3	−0.4	3.9	−0.6	2.2	−0.7	0.5	−0.3	−4.6	+0.1	−10.5	−0.2
Mitchel Field (Hempstead, Long Island), N. Y.[1] (29 m)	27	−0.7	+0.9	−1.9	+0.4	−3.2	+0.4	−4.3	+0.1	−5.4	+0.3	−6.7	+0.8	−8.6	+1	−14.0	+1.1		
Nashville, Tenn.[2] (180 m) #	30	2.7	+0.9	2.8	0.0	1.7	−0.3	0.2	−0.8	−0.9	−0.9	−2.5	−0.5	−4.5	−0.4	−9.0	−0.3	−15.4	−0.4
Norfolk, Va.[3] (10 m)	20	2.3	−1.7	2.7	−0.6	1.8	−0.1	0.0	−0.5	−0.8	0.0	−2.0	+0.6	−3.9	+0.7	−7.7	+1.5	−12.3	+2.3
Oakland, Calif.[2] (2 m) §	31	9.0	+0.7	11.8	+1.5	10.6	+1.5	8.9	+1.4	6.4	+1.3	3.8	+1.1	1.0	+1.0	−5.4	+0.9	−12.3	+0.7
Oklahoma City, Okla.[2] (391 m)	27	1.4	−0.6	2.5	−0.8	3.5	−1.5	2.7	−1.3	1.7	−0.7	0.1	−0.3	−2.0	+0.1	−7.0	+0.4	−13.3	+0.9
Omaha, Nebr.[2] (300 m)	31	−4.9	−0.7	−4.4	−1.0	−3.0	−1.2	−3.2	−2.3	−4.0	−2.0	−5.6	−1.5	−7.6	−1.1	−13.5	−1.2	−19.9	−1.1
Pearl Harbor, T. H.[3] (6 m)	31	20.6	−1.5	20.6	+0.5	17.3	+1.0	14.4	+0.9	12.8	+1.1	11.3	+1.4	9.4	+1.9	4.1	+2.2	−2.0	+1.7
Pensacola, Fla.[3] (13 m)	23	8.3	−0.7	9.5	−0.4	9.2	−0.4	8.4	−0.2	7.2	−0.1	5.5	+0.1	3.7	+0.3	−1.7	−0.1	−6.5	+0.6
St. Thomas, Virgin Islands,[3] (8 m)	31	25.7		21.3		17.6		14.6		13.2		12.1		9.8		4.6		−1.7	
Salt Lake City, Utah [2] (1,288 m)	31	−0.4						1.8		0.5		−2.0		−4.4		−9.3		−15.6	
San Diego, Calif.[3] (10 m)	31	10.3	−1.5	14.3	+1.1	12.7	+0.6	9.8	−0.1	7.6	−0.1	5.1	−0.2	2.4	−0.4	−3.5	−0.3	−9.8	−0.1
Sault Ste. Marie, Mich.[2] (221 m)	28	−8.9		−9.2		−10.9		−11.6		−12.1		−14.1		−15.8		−20.3		−26.2	
Scott Field (Belleville), Ill.[1] (135 m)	13	−4.5		−4.5		−4.8		−5.6		−5.9		−7.1		−8.8		−12.9		−19.3	
Seattle, Wash.[3] (10 m)	8	6.0		5.1		2.9		1.3		−0.5		−3.4		−6.0		−12.0			
Selfridge Field (Mount Clemens), Mich.[1] (177 m)	25	−6.1	−1.9	−6.3	−2.9	−7.9	−3.5	−9.4	−4.2	−10.3	−3.8	−11.3	−3.2	−13.2	−3.0	−18.0	−3.1	−23.6	−2.8
Spokane, Wash.[2] (597 m)	31	0.7	+0.5			−0.9	−1.1	−2.4	−2.2	−4.3	−2.7	−6.7	−2.9	−9.5	−2.9	−15.8	−3.0	−22.2	−3.0
Washington, D. C.[2] (13 m)	30	0.8	+0.1	1.4	+0.6	−0.1	+0.6	−1.4	+0.4	−2.2	+0.5	−4.0	+0.4	−6.4	−0.1	−11.4	−0.5	−17.1	+0.7
Wright Field (Dayton), Ohio [1] (244 m)	17	−4.6	−0.7	−4.4	−1.0	−4.6	−1.3	−4.6	−0.9	−6.1	−1.0	−7.7	−0.8	−9.6	−0.7	−13.8	−0.5	−19.3	−0.3

[1] Army.
[2] Weather Bureau.
[3] Navy.

December 1937.—Observations taken about 4 a. m. 75th meridian time, except by Navy stations along the Pacific coast and Hawaii where they are taken at dawn.

NOTE.—The departures are based on normals covering the following total number of observations made during the same month in previous years, including the current month (years of record are given in parentheses following the number of observations): Billings, 123 (4); Boston, 126 (6); Cheyenne, 124 (4); Chicago, 87 (3); El Paso, 93 (3); Fargo, 119 (4); Lakehurst, 93 (4); Maxwell Field, 98 (4); Mitchel Field, 97 (4); Nashville, #112 (4); Norfolk, 101 (5); Oakland, §81 (3); Oklahoma City, 114 (4); Omaha, 208 (7); Pearl Harbor, 137 (5); Pensacola, 171 (8); San Diego, 220 (9); Selfridge Field, 79 (3); Spokane, 116 (4); Washington, 154 (7); Wright Field, 82 (4).

#Combined with Murfreesboro data (ending June 26, 1937.
§Combined with Sunnyvale data (ending September 1935).

TABLE 2.—*Mean free-air relative humidities (R. H.), in percent, and specific humidities (q), in grams/kilogram, obtained by airplanes during December 1937. (Dep. represents departure from "normal" relative humidity)*

Stations	Number of observations	Surface q	Surface R. H. Mean	Surface R. H. Dep.	500 q	500 R. H. Mean	500 R. H. Dep.	1,000 q	1,000 R. H. Mean	1,000 R. H. Dep.	1,500 q	1,500 R. H. Mean	1,500 R. H. Dep.	2,000 q	2,000 R. H. Mean	2,000 R. H. Dep.	2,500 q	2,500 R. H. Mean	2,500 R. H. Dep.	3,000 q	3,000 R. H. Mean	3,000 R. H. Dep.	4,000 q	4,000 R. H. Mean	4,000 R. H. Dep.	5,000 q	5,000 R. H. Mean	5,000 R. H. Dep.
Barksdale Field, La	19	4.2	77	----	3.7	63	----	3.4	57	----	3.4	59	----	2.8	51	----	2.5	49	----	2.2	44	----	1.4	38	----	----	----	----
Billings, Mont	31	2.4	71	+3	----	----	----	----	----	----	2.5	57	0	2.3	56	+1	2.0	58	+1	1.8	61	+1	1.2	60	+1	0.8	59	+2
Boston, Mass	22	2.2	72	+1	2.0	71	+2	1.9	69	+1	1.9	69	+5	1.8	65	+7	1.6	60	+5	1.3	55	+1	1.0	52	0	----	----	----
Cheyenne, Wyo	31	2.7	72	+7	----	----	----	----	----	----	----	----	----	2.8	66	+5	2.6	61	+6	2.3	60	+6	1.5	57	+5	1.0	55	+5
Chicago, Ill	29	2.4	84	0	2.3	83	+3	2.1	74	+3	1.9	65	+2	1.8	61	+4	1.6	56	+4	1.5	55	+5	1.2	54	+6	0.8	55	+11
Coco Solo, Canal Zone	19	17.8	93	----	16.8	91	----	14.5	87	----	12.5	84	----	10.9	81	----	8.2	67	----	6.4	58	----	4.5	53	----	3.0	49	----
El Paso, Tex	31	4.5	77	+4	----	----	----	----	----	----	4.3	58	+1	3.6	56	+4	3.2	53	+3	2.6	48	+4	1.7	41	+5	1.0	37	+5
Fargo, N. Dak	31	1.0	75	−6	1.2	75	−3	1.5	69	−2	1.6	64	+1	1.6	63	+5	1.5	62	+6	1.3	62	+9	0.9	50	+8	0.6	58	+9
Kelly Field, Tex	8	6.4	80	----	6.4	71	----	5.9	74	----	5.7	74	----	4.9	66	----	4.6	69	----	4.2	66	----	2.6	59	----	2.4	73	----
Lakehurst, N. J	22	2.5	72	−3	2.3	63	−5	2.1	61	−5	1.8	54	−4	1.7	54	0	1.6	54	0	1.3	55	+3	0.9	54	+5	0.7	52	+5
Maxwell Field, Ala	28	4.7	75	−2	4.0	62	−2	3.9	60	+2	3.4	50	+3	3.1	49	+7	2.6	44	+6	2.5	45	+8	2.0	45	+10	1.4	43	+10
Mitchel Field, N. Y	27	2.6	74	−3	2.4	70	−2	2.2	67	−1	2.0	62	+1	1.8	56	+1	1.7	53	+1	1.5	49	+1	1.1	52	+6	----	----	----
Nashville, Tenn	30	3.8	81	−2	3.8	77	+3	3.6	76	+8	3.1	68	+8	2.8	62	+9	2.5	59	+9	2.2	59	+12	1.8	56	+12	1.0	50	+8
Norfolk, Va	20	3.3	75	+4	3.0	62	0	2.8	57	−1	2.5	55	+4	2.3	52	+7	2.1	48	+5	1.8	46	+6	1.3	42	+8	1.0	41	+10
Oakland, Calif	31	6.0	85	+7	5.6	62	−2	5.0	56	−2	4.0	48	−2	3.5	47	0	3.0	43	0	2.2	39	−2	1.5	36	−2	1.0	39	0
Oklahoma City, Okla	27	3.7	84	+2	3.7	76	0	3.4	63	+1	3.3	60	+3	3.0	55	+4	2.7	51	+4	2.2	47	+4	1.5	43	+3	1.0	40	+2
Omaha, Nebr	31	2.2	84	−1	2.3	79	−1	2.4	71	+3	2.3	66	+10	2.1	59	+8	1.9	58	+10	1.8	57	+10	1.2	58	+12	0.8	55	+10
Pearl Harbor, Territory of Hawaii	31	12.9	86	+7	11.9	75	−1	10.7	78	−2	9.2	76	+2	7.1	61	0	5.2	46	−3	3.7	35	−6	2.0	25	−7	1.3	23	−5
Pensacola, Fla	23	5.7	86	+1	5.8	76	+1	5.0	63	−2	4.6	56	−2	3.6	45	−6	2.8	38	−10	2.4	34	−11	1.7	31	−9	1.1	28	−11
St. Thomas, Virgin Islands	31	15.4	75	----	14.8	89	----	13.1	94	----	10.9	80	----	8.3	70	----	5.4	46	----	3.8	35	----	1.5	18	----	1.0	16	----
Salt Lake City, Utah	31	3.6	86		----	----	----	----	----	----	3.8	73	----	3.3	67	----	2.8	65	----	2.4	60	----	1.7	53	----	1.1	53	----
San Diego, Calif	31	6.5	84	+12	7.0	66	+5	6.0	59	+8	5.0	56	+9	4.1	50	+10	3.4	47	+11	3.0	46	+14	1.9	41	+12	1.1	39	+9
Sault Ste. Marie, Mich	28	1.7	83	----	1.8	85	----	1.6	83	----	1.4	71	----	1.2	61	----	1.0	62	----	1.0	62	----	0.7	62	----	0.4	55	----
Scott Field, Ill	13	1.9	71	----	1.7	60	----	1.6	54	----	1.6	54	----	1.7	55	----	1.7	56	----	1.5	55	----	1.0	46	----	0.7	42	----
Seattle, Wash	8	5.0	87	----	4.6	80	----	3.7	72	----	3.4	67	----	2.6	55	----	1.9	49	----	1.5	44	----	0.8	34	----	----	----	----
Selfridge Field, Mich	25	2.1	85	0	2.0	82	+2	1.7	74	0	1.5	69	+6	1.4	63	+7	1.2	55	+7	1.0	53	+6	0.8	51	+6	0.6	51	+5
Spokane, Wash	31	3.6	86	0	----	----	----	3.5	88	+1	3.2	82	+5	2.6	74	+4	2.1	68	+1	1.8	66	+1	1.2	65	+5	0.7	62	+5
Washington, D. C	30	2.9	72	0	2.7	62	−3	2.5	60	−1	2.5	62	+3	2.4	60	+6	2.2	57	+7	1.8	54	+9	1.1	44	+1	0.7	38	−1
Wright Field, Ohio	17	2.2	81	−1	2.3	76	−2	2.0	64	−4	1.8	57	0	1.7	56	+4	1.7	57	+7	1.5	55	+8	1.2	57	+11	0.8	51	+7

Altitude (meters) m. s. l.

TABLE 3.—*Mean free-air barometric pressures (P), in mb, and equivalent potential temperatures (Θe), in °A., obtained by airplanes during December 1937*

Station	Number of observations	Surface P	Surface Θe	500 P	500 Θe	1,000 P	1,000 Θe	1,500 P	1,500 Θe	2,000 P	2,000 Θe	2,500 P	2,500 Θe	3,000 P	3,000 Θe	4,000 P	4,000 Θe	5,000 P	5,000 Θe
Barksdale Field, La	19	1,018	289	963	292	906	296	852	300	801	302	753	304	707	307	623	309	----	----
Billings, Mont	31	891	286	----	----	----	----	846	293	795	297	746	298	700	299	614	302	537	305
Boston, Mass	22	1,019	275	957	277	898	281	842	285	790	290	741	293	695	296	609	301	----	----
Cheyenne, Wyo	31	810	295	----	----	----	----	----	----	797	298	746	302	702	304	617	307	541	308
Chicago, Ill	29	998	275	959	277	900	282	844	287	792	291	742	294	696	297	610	303	535	307
Coco Solo, Canal Zone	19	1,008	347	954	348	901	344	850	341	802	340	755	335	712	333	630	332	557	332
El Paso, Tex	31	884	300	----	----	----	----	851	306	801	307	753	309	707	311	624	313	548	315
Fargo, N. Dak	31	986	263	958	267	897	276	841	282	788	287	738	291	692	293	606	298	529	301
Kelly Field, Tex	8	999	300	965	302	908	306	854	300	804	311	755	313	710	316	626	317	551	320
Lakehurst, N. J	22	1,017	277	958	281	900	284	844	288	793	290	743	294	697	296	611	298	536	305
Maxwell Field, Ala	28	1,017	291	964	294	907	298	853	302	802	304	753	307	708	310	624	314	549	317
Mitchel Field, N. Y	27	1,017	278	958	281	900	285	844	288	792	292	743	295	697	298	611	302	----	----
Nashville, Tenn	30	1,001	286	962	290	904	293	850	296	798	299	749	301	708	305	618	309	543	311
Norfolk, Va	20	1,022	282	962	287	903	291	849	293	798	298	748	301	703	304	618	309	544	314
Oakland, Calif	31	1,019	297	960	304	904	307	851	307	801	308	752	310	708	310	623	312	549	314
Oklahoma City, Okla	27	975	287	962	289	905	294	850	299	799	302	750	305	705	307	620	310	546	312
Omaha, Nebr	31	985	275	960	278	902	285	846	290	794	294	745	297	699	300	613	303	537	306
Pearl Harbor, Territory of Hawaii	31	1,014	328	958	331	904	330	852	328	802	326	755	324	711	323	629	323	556	325
Pensacola, Fla	23	1,023	295	964	301	908	305	854	308	804	309	756	310	710	313	627	316	553	320
St. Thomas, Virgin Islands	31	1,015	341	959	340	905	336	853	333	804	329	757	325	713	324	632	322	558	324
Salt Lake City, Utah	31	874	294	----	----	----	----	852	299	800	301	751	303	704	305	618	309	542	311
San Diego, Calif	31	1,016	300	959	311	904	312	850	311	801	312	753	313	708	314	625	315	550	317
Sault Ste. Marie, Mich	28	990	270	955	272	895	275	838	279	785	283	735	286	688	289	601	295	524	298
Scott Field, Ill	13	1,005	273	959	277	900	281	844	286	791	291	742	295	696	298	611	303	537	306
Seattle, Wash	8	1,021	291	962	294	904	294	850	297	798	298	748	299	703	300	617	302	----	----
Selfridge Field, Mich	25	999	273	958	276	899	278	842	281	790	286	739	289	693	292	607	297	530	302
Spokane, Wash	31	949	288	----	----	903	290	847	293	795	295	745	296	700	298	613	300	537	302
Washington, D. C	30	1,022	280	962	285	903	288	848	292	797	296	748	299	702	300	616	304	541	308
Wright Field, Ohio	17	994	275	962	278	902	282	846	287	794	290	744	294	698	297	612	302	536	307

Altitude (meters) m. s. l.

TABLE 4.—*Free-air resultant winds (meters per second) based on pilot-balloon observations made near 5 a. m. (E. S. T.) during December 1937*

[Wind from N=360°, E=90°, etc.]

Altitude (m) m. s. l.	Albuquerque, N. Mex. (1,554 m)		Atlanta, Ga. (309 m)		Billings, Mont. (1,088 m)		Boston, Mass. (15 m)		Cheyenne, Wyo. (1,873 m)		Chicago, Ill. (192 m)		Cincinnati, Ohio (153 m)		Detroit, Mich. (204 m)		Fargo, N. Dak. (274 m)		Houston, Tex. (21 m)		Key West, Fla. (11 m)		Medford, Oreg. (410 m)		Nashville, Tenn. (194 m)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°		°		°		°		°		°		°		°	
Surface	354	1.0	319	1.8	262	3.9	295	2.5	274	3.5	251	1.9	221	1.0	256	2.5	321	1.2	46	1.8	50	3.3	137	0.6	226	0.9
500			295	2.2			302	5.9			259	3.9	234	3.6	263	4.1	308	1.8	111	3.0	79	6.2	137	1.6	239	5.6
1,000			273	4.1			299	7.8			279	5.0	272	6.9	275	7.5	308	4.2	170	0.4	103	4.8	185	3.9	261	8.2
1,500			268	4.9	261	8.8	292	9.3			273	7.9	269	8.8	286	6.8	298	6.2	280	5.1	124	2.3	220	7.3	271	9.5
2,000	315	3.5	286	7.3	281	8.4	286	10.1	282	5.1	284	9.2	274	10.0	284	6.9	300	5.4	280	5.7	127	1.1	235	10.6	276	9.9
2,500	303	5.9	292	9.6	283	9.8	279	12.4	293	9.8	280	8.3			283	8.5	290	10.6	275	7.9	317	1.1			285	14.6
3,000	294	6.7	282	12.9	279	11.6	253	15.3	292	11.3							291	13.0	247	9.2	310	1.7				
4,000	296	10.4			291	12.9			294	11.6																
5,000	290	8.2							272	9.3																

Altitude (m) m. s. l.	Newark, N. J. (14 m)		Oakland, Calif. (8 m)		Oklahoma City, Okla. (402 m)		Omaha, Nebr. (306 m)		Pearl Harbor, Hawaii[1] (68 m)		Pensacola, Fla.[1] (24 m)		St. Louis, Mo. (170 m)		Salt Lake City, Utah (1,294 m)		San Diego, Calif. (15 m)		Sault Ste. Marie, Mich. (198 m)		Seattle, Wash. (14 m)		Spokane, Wash. (603 m)		Washington, D. C. (10 m)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°		°		°		°		°		°		°		°	
Surface	281	2.4	79	1.5	282	0.1	314	2.0	4	1.7	19	2.5	247	2.2	168	2.2	46	0.7	265	0.5	152	1.7	192	2.0	312	1.2
500	308	7.6	18	2.2	343	1.0	315	3.4	71	2.4	40	3.2	260	5.9			93	1.1	291	2.2	196	5.4			297	6.0
1,000	288	8.7	14	3.0	303	4.9	304	6.4	100	2.4	271	2.8	274	9.3			123	0.8	307	5.2	212	3.7	193	3.6	288	7.4
1,500	282	13.2	332	1.9	302	6.9	306	8.1	115	1.3	293	4.9	276	9.4	187	3.0	318	1.4	325	4.2	236	4.8	218	8.0	270	9.0
2,000	265	14.1	308	1.9	298	8.4	300	9.5	301	0.6	305	5.1	290	11.9	224	2.6	343	2.6			256	5.5	231	9.5	273	10.6
2,500	262	13.1	286	2.4	299	9.5	294	10.1	354	1.8	291	5.6	284	14.3	261	3.7	330	3.2					251	9.4	276	11.3
3,000			295	3.1	300	10.1	300	11.1	318	1.9			298	12.7	274	6.0	349	4.1							275	13.3
4,000			270	7.3					305	6.6					293	6.5	356	6.5								
5,000									297	10.6					318	5.6	323	0.2								

[1] Navy stations.

TABLE 5.—*Maximum free-air wind velocities (meters per second) for different sections of the United States, based on pilot balloon observations during December 1937*

Section	Surface to 2,500 meters (m. s. l.)					Between 2,500 and 5,000 meters (m. s. l.)					Above 5,000 meters (m. s. l.)				
	Maximum velocity	Direction	Altitude (m), m. s. l.	Date	Station	Maximum velocity	Direction	Altitude (m), m. s. l.	Date	Station	Maximum velocity	Direction	Altitude (m), m. s. l.	Date	Station
Northeast[1]	36.0	NNW	1,360	14	Boston, Mass.	36.4	WSW	4,600	12	Boston, Mass.	36.0	WSW	6,280	1	Cleveland, Ohio.
East Central[2]	32.7	SW	1,360	18	Washington, D. C.	42.0	WSW	4,890	19	Knoxville, Tenn.	42.2	WSW	5,070	19	Knoxville, Tenn.
Southeast[3]	26.8	WSW	1,720	23	Jacksonville, Fla.	38.0	WSW	4,480	9	Spartanburg, S. C.	33.1	WNW	6,480	12	Charleston, S. C.
North Central[4]	38.8	NNW	1,870	31	Bismarck, N. Dak.	35.2	WNW	2,530	25	Fargo, N. Dak.	43.1	NNW	6,850	10	Fargo, N. Dak.
Central[5]	35.8	W	2,500	8	Evansville, Ind.	41.6	W	3,820	25	Omaha, Nebr.	40.5	WNW	6,160	9	Omaha, Nebr.
South Central[6]	30.5	W	1,360	22	Brownsville, Tex.	37.1	WSW	4,810	24	Fort Worth, Tex.	45.4	W	6,610	18	Amarillo, Tex.
Northwest[7]	39.3	SW	1,770	26	Spokane, Wash.	43.4	NNW	5,000	21	Pendleton, Oreg.	49.0	NNW	5,580	21	Pendleton, Oreg.
West Central[8]	52.5	WSW	2,480	27	Cheyenne, Wyo.	52.2	WSW	2,670	27	Cheyenne, Wyo.	66.0	WNW	11,290	30	Redding, Calif.
Southwest[9]	41.4	SW	1,550	26	Havre, Mont.	64.2	NNE	3,910	20	Burbank, Calif.	80.4	NE	5,520	20	Las Vegas, Nev.

[1] Maine, Vermont, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, and northern Ohio.
[2] Delaware, Maryland, Virginia, West Virginia, southern Ohio, Kentucky, eastern Tennessee, and North Carolina.
[3] South Carolina, Georgia, Florida, and Alabama.
[4] Michigan, Wisconsin, Minnesota, North Dakota, and South Dakota.
[5] Indiana, Illinois, Iowa, Nebraska, Kansas, and Missouri.
[6] Mississippi, Arkansas, Louisiana, Oklahoma, Texas (except El Paso), and western Tennessee.
[7] Montana, Idaho, Washington, and Oregon.
[8] Wyoming, Colorado, Utah, northern Nevada, and northern California.
[9] Southern California, southern Nevada, Arizona, New Mexico, and extreme west Texas.

AEROLOGICAL OBSERVATIONS FOR THE YEAR 1937

[Aerological Division, D. M. LITTLE in Charge]

By LOYD A. STEVENS

In tables 1 to 3 below are shown the mean free-air temperatures, relative humidities, specific humidities, and equivalent potential temperatures obtained by airplane observations during the year 1937. Departures from normal for mean temperatures and relative humidities are given for nine stations where the length of record is 3 or more years. (See footnote to table.) Similar departures for specific humidity and equivalent potential temperature are not shown as these elements were not computed and tabulated previous to January 1937.

Due to the relatively short period on which the normal data are based at most stations, too much dependence should not be placed in the departures therefrom.

A summary of the aerological activities of the Weather Bureau during the year 1937 follows: Regular airplane flights were maintained at 12 stations in continental United States by private operators under contract with the Weather Bureau. Similar flights were made by the War Department in cooperation with the Weather Bureau at eight stations and by the Navy Department at nine

stations. The special airplane weather observations, made at Fairbanks, Alaska, during the 1936–37 winter months, with funds provided under the Bankhead-Jones Act, for the investigation of the structure of Polar Anticyclonic air masses, were resumed on September 16, 1937, and will be continued through the present winter season. These observations are being supplemented this season by radio-meterograph observations.

Much experimental work was done toward the perfection of the radiometeorograph for making upper-air soundings and during the latter part of the year a daily schedule of such observations was inaugurated at Boston, Mass., and Burbank, Calif.

During the international month of August, 38 sounding balloons, to which recording meteorographs were attached, were released at Omaha, Nebr. Thirty-four of the meteorographs have been recovered and, although all the records have not been computed, it appears that at least 25 of them reached altitudes of 20 kilometers or more above sea level. Two-theodolite observations, by which the upper-air wind currents were measured, were also made on 32 of the sounding-balloon ascents.

Pilot-balloon observations were made daily at 77 stations, including 3 in Alaska and 1 at San Juan, P. R. By the end of the year four observations were being made daily at nearly all of the stations located in continental United States.

Experimental two-theodolite observations were made during the year on a larger size (100-gram), faster-rising, pilot balloon with a view to its adoption in place of the 30-gram balloon now used for upper-air wind measurements.

TABLE 1.—*Mean free-air temperatures (t), °C. obtained by airplanes during the year 1937. (Dep. represents departure from "normal" temperature)*

Stations [4]	Altitude (meters) m. s. l. — Surface			500		1,000		1,500		2,000		2,500		3,000		4,000		5,000	
	Number of observations	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.
Barksdale Field [1] (Shreveport), La. (52 m)	326	14.9	------	15.5	------	13.9	------	12.0	------	9.7	------	7.2	------	4.6	------	−0.8	------	------	------
Boston, Mass.[1] (5 m)	312	7.9	------	7.8	------	5.7	------	3.8	------	1.9	------	−0.1	------	−2.3	------	−7.4	------	------	------
Cheyenne, Wyo.[2] (1,873 m)	351	3.4	−0.2	------	------	------	------	------	------	4.7	−0.2	4.4	−0.6	1.6	−0.5	−5.3	−0.5	−12.7	−0.5
Coco Solo, Canal Zone [3] (15 m)	299	25.0	------	23.2	------	20.6	------	18.0	------	15.5	------	13.4	------	11.0	------	5.1	------	−0.7	------
El Paso, Tex.[2] (1,194 m)	364	13.4	------	------	------	------	------	16.0	------	13.5	------	10.4	------	7.1	------	0.3	------	−6.3	------
Fargo, N. Dak.[2] (274 m)	356	1.0	+0.1	3.3	+0.2	3.3	+0.1	2.1	−0.1	0.4	−0.1	−1.9	−0.2	−4.4	−0.1	−10.0	0.0	−16.3	+0.1
Lakehurst, N. J.[3] (39 m)	283	7.7	------	8.7	------	6.5	------	4.7	------	2.5	------	0.2	------	−2.3	------	−7.9	------	------	------
Mitchel Field (Hempstead, L. I.), N. Y.[1] (29 m)	297	8.2	+0.2	8.8	+0.3	7.0	+0.2	5.2	+0.2	3.3	+0.2	1.2	+0.2	−1.2	+0.2	−6.4	+0.3	------	------
Nashville, Tenn.[2] (180 m) #	356	12.0	+0.4	13.0	0.0	11.3	−0.3	9.0	−0.6	6.8	−0.6	4.5	−0.5	2.1	−0.4	−3.4	−0.3	−9.3	−0.1
Oakland, Calif.[3] (2 m)	364	11.1	------	12.7	------	13.2	------	11.4	------	9.0	------	6.3	------	3.4	------	−2.8	------	−9.3	------
Oklahoma City, Okla.[2] (391 m)	356	11.8	−0.4	13.1	−0.3	13.5	−0.5	12.0	−0.4	9.9	−0.3	7.1	−0.3	4.2	−0.2	−2.3	−0.1	−9.1	−0.1
Pearl Harbor, Territory of Hawaii [3] (6 m)	362	21.5	−1.6	20.4	−0.4	17.1	0.0	14.4	+0.1	12.4	+0.4	10.9	+0.4	8.9	+0.4	4.1	+0.7	−1.7	+0.8
St. Thomas, Virgin Islands [3] (8 m)	352	26.4	------	23.0	------	19.7	------	16.9	------	14.6	------	12.6	------	10.4	------	5.1	------	−0.5	------
Salt Lake City, Utah [1] (1,288 m)	360	7.1	------	------	------	------	------	10.3	------	8.5	------	5.4	------	2.2	------	−4.2	------	−10.6	------
San Diego, Calif.[3] (10 m)	343	13.9	−2.2	14.0	−1.1	15.1	−0.5	14.0	−0.2	12.0	−0.4	9.5	−0.1	6.7	−0.1	0.6	+0.1	−6.0	+0.1
Sault Ste. Marie, Mich.[2] (221 m)	351	2.4	------	3.6	------	1.9	------	0.0	------	−1.6	------	−3.6	------	−5.9	------	−11.3	------	−17.4	------
Spokane, Wash.[2] (597 m)	362	5.6	------	------	------	8.0	------	6.2	------	3.4	------	0.2	------	−3.0	------	−9.4	------	−15.9	------
Washington, D. C.[3] (13 m)	318	10.5	−0.4	10.7	+0.3	8.6	−0.1	6.4	−0.3	4.3	−0.4	2.2	−0.4	−0.4	−0.8	−5.7	−0.9	−11.4	−1.0
Wright Field (Dayton), Ohio [1] (244 m)	299	6.9	−0.4	8.5	−0.4	7.5	−0.6	5.6	−0.7	3.5	−0.8	1.3	−0.8	−1.0	−0.7	−6.2	−0.5	−12.3	−0.4

[1] Army. [2] Weather Bureau. [3] Navy. [4] Data for stations having less than 12 months of observations have been omitted.

Year 1937.—Observations taken about 4 a. m. 75th meridian time, except by Navy stations along the Pacific coast and Hawaii where they are taken at dawn.

NOTE.—The departures are based on normals covering the following total number of years of record including the current year (where the number of years is not the same for each month, the minimum and the maximum numbers are given): Cheyenne (3–4), Fargo (3–4), Mitchel Field (3–4), Nashville (3–4), Oklahoma City (3–4), Pearl Harbor (4–7), San Diego (8–9), Washington (5–11), Wright Field, (3–4).

#Combined with Murfreesboro data (ending June 26, 1937).

TABLE 2.—*Mean free-air relative humidities (R. H.), in percent, and specific humidities (q), in grams/kilogram, obtained by airplanes during the year 1937. (Dep. represents departure from "normal" relative humidity)*

Station	Altitude (meters) m. s. l. — Surface				500			1,000			1,500			2,000			2,500			3,000			4,000			5,000		
	Number of observations	q	R. H. Mean	R. H. Dep.	q	R. H. Mean	R. H. Dep.	q	R. H. Mean	R. H. Dep.	q	R. H. Mean	R. H. Dep.	q	R. H. Mean	R. H. Dep.	q	R. H. Mean	R. H. Dep.	q	R. H. Mean	R. H. Dep.	q	R. H. Mean	R. H. Dep.	q	R. H. Mean	R. H. Dep.
Barksdale Field, La.	326	9.6	82	----	8.2	65	----	7.2	59	----	6.4	56	----	5.4	52	----	4.5	50	----	3.8	47	----	2.7	43	----	----	----	----
Boston, Mass.	312	6.0	77	----	5.5	69	----	5.0	67	----	4.5	66	----	4.0	63	----	3.4	59	----	2.8	56	----	2.0	51	----	----	----	----
Cheyenne, Wyo.	351	4.8	67	+2	----	----	----	----	----	----	----	----	----	4.8	62	+1	4.3	55	+2	3.6	54	+2	2.6	54	+2	1.8	57	+4
Coco Solo, Canal Zone	299	18.2	92	----	16.7	89	----	14.7	87	----	12.9	85	----	11.2	81	----	8.9	70	----	7.0	62	----	5.1	60	----	3.7	57	----
El Paso, Tex.	364	6.0	50	----	----	----	----	----	----	----	6.0	42	----	5.3	41	----	4.7	41	----	4.1	42	----	3.1	44	----	2.2	43	----
Fargo, N. Dak.	356	4.7	79	−1	4.8	70	0	4.4	65	+1	4.0	62	+2	3.5	59	+2	3.0	57	+3	2.6	57	+3	1.8	54	+3	1.2	53	+4
Lakehurst, N. J.	283	6.4	82	----	5.5	64	----	4.8	61	----	4.3	59	----	3.7	56	----	3.3	55	----	2.8	53	----	1.9	48	----	----	----	----
Mitchel Field, N. Y.	297	6.5	81	−1	6.3	73	0	5.8	70	+1	5.2	67	0	4.6	64	0	4.0	61	+1	3.4	58	+2	2.2	52	0	----	----	----
Nashville, Tenn.	356	8.1	82	−1	7.5	70	0	7.0	69	+1	6.1	65	0	5.0	59	−1	4.2	55	0	3.5	52	0	2.3	46	−1	1.5	41	−2
Oakland, Calif.	364	7.1	85	----	7.0	71	----	5.7	55	----	4.5	47	----	3.6	42	----	2.9	38	----	2.4	36	----	1.7	36	----	1.2	36	----
Oklahoma City, Okla.	356	7.9	77	+2	8.0	70	0	7.3	60	0	6.5	55	+1	5.7	52	+1	4.9	51	+2	4.2	50	+3	2.8	49	+3	1.8	47	+3
Pearl Harbor, Territory of Hawaii	362	13.2	83	+6	12.3	78	+2	11.3	83	+3	9.6	79	+3	7.5	67	+2	5.4	50	−1	4.1	41	+1	2.4	29	0	1.6	27	+1
St. Thomas, Virgin Islands	352	16.8	79	----	16.3	88	----	14.0	88	----	11.6	82	----	9.4	72	----	7.1	58	----	5.4	48	----	3.3	39	----	2.2	33	----
Salt Lake City, Utah	360	5.2	66	----	----	----	----	----	----	----	5.7	57	----	4.9	54	----	4.3	55	----	3.7	56	----	2.8	59	----	2.1	59	----
San Diego, Calif.	343	8.5	83	+8	8.2	77	+5	6.9	57	+4	5.4	47	+3	4.4	41	+4	3.6	37	+4	2.2	36	+4	2.3	34	+4	1.5	33	+4
Sault Ste. Marie, Mich.	351	4.7	84	----	4.7	75	----	4.3	73	----	3.9	70	----	3.4	64	----	2.8	60	----	2.4	58	----	1.7	55	----	1.1	51	----
Spokane, Wash.	362	5.2	78	----	----	----	----	5.0	64	----	4.4	61	----	4.0	62	----	3.5	64	----	3.0	63	----	1.9	60	----	1.2	57	----
Washington, D. C.	318	7.2	78	+5	6.2	64	0	5.5	62	+2	4.9	61	+2	4.3	59	+2	3.7	55	+2	3.0	52	+2	2.0	46	+1	1.3	40	0
Wright Field, Ohio	299	6.3	84	+1	6.1	73	0	5.6	66	0	4.9	63	0	4.1	58	0	3.4	54	0	2.8	51	−1	2.0	47	−1	1.3	45	−1

TABLE 3.—*Mean free-air barometric pressures (P), in mb, and equivalent potential temperatures (Θe), in °A. obtained by airplanes during the year 1937*

Stations	Surface			500		1,000		1,500		2,000		2,500		3,000		4,000		5,000	
	Number of observations	P	Θe	P	Θe	P	Θe	P	Θe	P	Θe	P	Θe	P	Θe	P	Θe	P	Θe
Barksdale Field, La.	326	1,012	314	959	315	904	316	852	318	802	318	755	318	710	318	628	320		
Boston, Mass.	312	1,016	296	957	300	901	301	847	304	796	305	748	307	703	308	618	312		
Cheyenne, Wyo.	351	811	308							798	311	750	314	706	315	622	316	547	316
Coco Solo, Canal Zone	299	1,009	349	953	348	901	345	849	343	801	341	754	338	711	335	629	334	557	334
El Paso, Tex.	364	882	315					850	321	801	322	754	322	710	322	628	322	554	324
Fargo, N. Dak.	356	983	288	956	294	899	298	845	300	794	303	746	304	700	306	615	308	540	311
Lakehurst, N. J.	283	1,013	297	958	301	902	302	848	304	798	305	750	307	704	308	620	310		
Mitchel Field, N. Y.	297	1,015	298	959	303	902	305	848	307	798	309	750	310	704	311	621	313		
Nashville, Tenn.	356	997	308	960	311	904	313	851	314	801	314	753	314	708	315	625	316	551	318
Oakland, Calif.	364	1,016	302	958	309	903	312	850	312	801	312	753	312	709	313	625	315	551	317
Oklahoma City, Okla.	356	970	310	958	313	903	316	850	318	801	319	754	319	709	319	626	319	552	319
Pearl Harbor, Territory of Hawaii	362	1,015	330	959	332	905	331	853	329	804	326	757	324	714	324	632	324	558	326
St. Thomas, Virgin Islands	352	1,016	346	961	346	907	342	855	337	806	354	759	330	715	329	634	328	560	329
Salt Lake City, Utah	360	871	307					849	314	800	315	752	315	707	316	624	317	549	319
San Diego, Calif.	343	1,014	309	958	314	902	317	850	317	801	317	754	318	709	319	627	321	554	322
Sault Ste. Marie, Mich.	351	989	289	956	294	898	296	844	298	792	300	744	302	698	304	613	307	538	309
Spokane, Wash.	362	946	298			901	304	848	306	797	307	749	308	704	308	619	309	544	311
Washington, D. C.	318	1,018	302	960	305	903	306	850	307	799	309	752	310	706	311	622	313	547	316
Wright Field, Ohio	290	989	298	958	302	902	305	849	306	798	307	750	308	705	310	621	312	546	315

Altitude (meters) m. s. l.

RIVERS AND FLOODS

[River and Flood Division, MERRILL BERNARD in Charge]

By BENNETT SWENSON

The outstanding flood during December 1937 occurred in the Sacramento River. A report of this flood appears as a separate article in this REVIEW (pp. 441).

Moderate floods in the northern portion of the Ohio Basin resulted generally from moderately heavy rains from December 15–18, falling on a snow covering, and at a time when the rivers were largely frozen. The run-off from rain and melted snow was heavy, principally in the Allegheny and Monongahela Basins and in the northern tributaries of the Ohio from the Beaver to the Muskingum River. A breaking up of the ice resulted, but no serious damage occurred.

The snow cover was heaviest over the Allegheny Basin, with depths of 7 to 9 inches in the northern portion. In the section between the Clarion and Kiskiminetas Rivers the snow depth averaged from 3 to 6 inches. Over the Monongahela Basin there was from 1 to 2 inches of snow on the ground, generally, and in the mountains about 6 inches.

Flood stages were not reached except in the lower 60 miles of the Allegheny, in the Ohio between Pittsburgh, Pa., and Wheeling, W. Va., and at the mouth of the Muskingum.

The river at Pittsburgh reached a crest of 27.5 feet at 5 a. m. of the 19th and then began to fall slowly. The damage was slight, estimated at about $500 along the Allegheny River and $2,000 in the Ohio between Pittsburgh and Wheeling.

A moderate rise occurred in the Muskingum River, and the crest in that stream reached the mouth in time to meet the Ohio crest. This resulted in a stage of 35.1 feet at Marietta, Ohio, on December 20, 0.1 foot above flood stage.

Moderate flooding occurred in the White and Wabash Rivers but no appreciable damage resulted.

Light to moderate floods during the month were reported in portions of the Red Basin, and the upper St. Francis and Trinity Rivers. Damages of consequence were estimated as follows: Ouachita River, $14,000, and Trinity River, $5,000.

A moderately severe flood occurred during the latter part of the month in the middle and northern portions of the Willamette Basin in Oregon. The flood resulted from heavy precipitation during the period December 26–30, following above-normal precipitation in November and early December. Three inches of rainfall occurred during a 24-hour period at a number of stations; and Falls City, Oreg., on the Luckiamute River, reported 5.50 inches on the 27th, and 4.48 inches on the 29th, with a total of 14.12 inches in 4 days. The greatest 24-hour amount at Portland, Oreg., was 5.01 inches.

Considerably more damage was caused by the high water and heavy rains than usually occurs when the Willamette River stages are much higher. This may be attributed to the high stages reached in the tributaries that are normally nothing more than small creeks; also, to the heavy concentration of precipitation.

The streams that probably were overloaded the most were the Luckiamute, Marys, Molalla, Pudding, Tualatin, and Yamhill Rivers. Of these streams the Molalla and Tualatin contributed much more water than usual. At some points in the Tualatin Valley the water was higher than the December 1933 flood, which was the highest in many years in those rivers.

Losses from the flood were confined mostly to the destruction of bridges and damage to highways by slides and washouts, loss of fences and the deposition of debris on tillable lands, and the suspension of business and loss of wages. The total loss is estimated at $127,800.

Unusually low stages prevailed during December in the Missouri and Mississippi Rivers. At St. Charles, Mo., on the Missouri, and at Grafton and Alton, Ill., and St. Louis, Mo., on the Mississippi, new all-time low stages were established. The lowest stage reached at St. Louis was 5.5 feet below zero on December 12 and 13. Ice conditions were largely the cause of the low stages.

Table of flood stages during December 1937

[All dates in December unless otherwise specified]

River and station	Flood stage	Above flood stages—dates From—	Above flood stages—dates To—	Crest Stage	Crest Date
ATLANTIC SLOPE DRAINAGE					
	Feet			*Feet*	
Santee: Rimini, S. C.	12	18	19	12.2	19
		30	(1)	12.8	31
MISSISSIPPI SYSTEM					
Ohio Basin					
Allegheny:					
Lock No. 8, near Mosgrove, Pa.	24	18	19	26.2	18
Lock No. 5, Schenley, Pa.	24	18	19	29.7	18
Lock No. 4, Natrona, Pa.	24	18	19	27.4	18
Lock No. 3, Acmetonia, Pa.	25	18	19	28.0	18, 19
Walhonding: Walhonding, Ohio	8	18	18	8.0	18
Muskingum: Lock No. 1, Marietta, Ohio (lower gage)	35	20	20	35.1	20
Scioto: La Rue, Ohio	11	18	18	12.8	18
West Fork of White:					
Anderson, Ind.	8	Nov. 29	1	8.3	Nov. 30
		17	25	13.3	18
Noblesville, Ind.	14	18	19	14.1	18, 19
Elliston, Ind	18	18	25	25.0	21, 22
Edwardsport, Ind.	12	18	27	18.7	23, 24
East Fork of White: Seymour, Ind.	14	18	21	16.1	19, 20
White:					
Petersburg, Ind.	16	20	28	20.9	26
Hazleton, Ind.	16	20	29	21.0	27
Wabash:					
Lafayette, Ind.	11	18	20	12.5	19
Covington, Ind.	16	20	21	18.7	20
Ohio:					
Pittsburgh, Pa.	25	18	19	27.5	19
Dam No. 7, Midland, Pa.	30	18	20	36.0	19
Dam No. 12, near Wheeling, W. Va.	36	19	20	37.4	19
Arkansas Basin					
Petit Jean: Danville, Ark.	20	18	20	21.1	19

[1] Continued at end of month.

Table of flood stages during December, 1937—Continued

River and station	Flood stage	Above flood stages—dates From—	Above flood stages—dates To—	Crest Stage	Crest Date
MISSISSIPPI SYSTEM					
Red Basin	*Feet*			*Feet*	
Ouachita: Camden, Ark.	26	28	Jan. 5	30.1	Jan. 1
Sulphur:					
Ringo Crossing, Tex.	20	17	20	24.4	18
Naples, Tex.	22	22	(1)	27.7	31
Cypress: Jefferson, Tex.	18	30	(1)	23.3	31
Lower Mississippi Basin					
Big Lake Outlet: Manila, Ark.	10	30	(1)	10.3	31
St. Francis: Fisk, Mo.	20	19	21	22.1	20
WEST GULF OF MEXICO DRAINAGE					
Trinity: Trinidad, Tex.	28	29	(1)	29.7	30
PACIFIC SLOPE DRAINAGE					
Sacramento Basin					
Stony Creek: St. John, Calif.	12	11	12	12.0	11, 12
North Fork of Yuba: Colgate, Calif.	14	10	11	22.0	10
Feather: Oroville, Calif.	25	11	11	26.3	11
Sacramento:					
Kennett, Calif.	25	11	11	29.0	11
Red Bluff, Calif.	23	11	12	32.0	11
Hamilton City, Calif.	22	11	12	22.8	11
Knights Landing, Calif.	30	12	17	32.6	14
Columbia Basin					
Santiam: Jefferson, Oreg.	10	29	31	13.5	30
South Yamhill: Willamina, Oreg.	8	27	30	14.0	27
Willamette:					
Harrisburg, Oreg.	10	12	13	11.4	12
Salem, Oreg.	20	30	31	21.5	31
Oregon City, Oreg.	12	29	(1)	16.3	31
Portland, Oreg.	18	30	31	19.0	30
Columbia: Vancouver, Wash.	15	30	31	15.8	31

[1] Continued at end of month.

WEATHER ON THE ATLANTIC AND PACIFIC OCEANS

[The Marine Division, I. R. TANNEHILL in Charge]

NORTH ATLANTIC OCEAN, DECEMBER 1937

By H. C. HUNTER

Atmospheric pressure.—The pressure situation during December was mainly like that of November, the northern region having decidedly high pressure compared with normal, while pressure below normal was the rule in the Bermuda-West Indies region. The notable change was in the southeastern areas, where slightly above normal December pressure succeeded the considerably below normal November pressure. At Horta the November average, a quarter inch under normal, gave way to a December average 0.04 inch above normal; the mean of the latter month (30.18 inches) being the highest among those shown in table 1.

Over the southern region and the waters adjacent to northwestern Europe pressure was almost everywhere higher during the second half of the month than during the first half. A different situation is noted for the Labrador-eastern Canada section, where the first 12 days had mainly high pressure and the period from 13th to 23d, low pressure.

The extremes of pressure in the vessel reports at hand are 30.67 and 28.69 inches. The higher mark was noted on the American steamship *Scanstates*, at noon of the 28th, near 58° N., 12° W. A slightly higher reading was made next day at the island station of Lerwick, as shown in table 1. The lower mark was recorded on the American steamship *Scanpenn*, early on the 21st, near 53° N., 37½° W.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure (sea level) at selected stations for the North Atlantic Ocean and its shores, December 1937*

Stations	Average pressure	Departure	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Julianehaab, Greenland	29.73	+0.25	30.56	7	29.02	22
Reykjavik, Iceland	29.70	+.23	30.39	28	28.85	22
Lerwick, Shetland Islands	29.90	+.18	30.71	29	29.26	5, 14
Valencia, Ireland	29.90	−.04	30.62	27	29.09	13
Lisbon, Portugal	30.13	+.02	30.45	26	29.68	8
Madeira	30.10	+.01	30.33	5	29.74	8
Horta, Azores	30.18	+.04	30.60	12	29.80	18
Belle Isle, Newfoundland	29.95	+.21	30.52	3	29.28	22
Halifax, Nova Scotia	30.01	+.06	30.58	28	29.56	14
Nantucket	30.06	+.01	30.58	27	29.14	7
Hatteras	30.15	+.02	30.52	27	29.50	6
Bermuda	30.06	−.06	30.36	28	29.42	4
Turks Island	30.00	−.03	30.12	27	29.86	9
Key West	30.08	0.00	30.22	27	29.77	6
New Orleans	30.17	+.04	30.45	2	29.71	17

NOTE.—All data based on a. m. observations only, with departures compiled from best available normals related to time of observation, except Hatteras, Key West, Nantucket, and New Orleans, which are 24-hour corrected means.

Cyclones and gales.—A considerable number of gales occurred, but reports available show none of forces 11 or 12. The absence of gales of these intensities is unusual in December. Several whole gales (force 10) were recorded, and it is noteworthy that more than two-thirds of these were met during the final 10 days of the month. Storm activity was at a minimum from the 7th to 12th.

A notable LOW of early December was centered the forenoon of the 2d about midway between Bermuda and

the northern Bahamas, with little strength; it moved thence to the northeastward, gaining in force, and on the 4th was central north of Bermuda, as chart IX shows. Thence it moved on to near Nova Scotia on the 5th, and then northwestward to unite with a cyclone advancing from the west; thereafter this center remained over the land and became less energetic.

About this time prevailing pressure was quite high over the South Atlantic, Gulf, and Plains States, and north winds were frequently encountered by vessels traversing the eastern Gulf of Mexico or the western Caribbean Sea.

On the 23d and 24th a vigorous storm from the interior of Canada developed still greater strength to the eastward of Newfoundland and caused strong to whole gales near mid-ocean along the steamship lanes to northwestern Europe. By the 26th, however, this LOW had turned northward to unite with another affecting the Iceland-Greenland area, as appears on chart X. This chart shows another important LOW central a short distance to southeastward of Newfoundland; it had resulted from the uniting near Cape Cod of two storms not especially strong, one coming from the South Atlantic States and the other from the Lake Region. From the vicinity of Newfoundland the center traveled north-northeastward to a position slightly to eastward of Cape Farewell, and the LOW as a whole became much elongated along a north-south line, so that important gales were met near mid-ocean about the 28–29th.

On the last 3 days of the month still another low-pressure system caused gales of considerable strength to southwestward, southward, and eastward of Newfoundland.

Fog.—As usually happens during December, fog was of infrequent occurrence for the most part. The northwestern Gulf of Mexico was an exception, for the 5°-square, 25° to 30° N., 90° to 95° W., furnished reports of 7 days with fog, all of them later than the 23d. This exceeds the total for any other portion of the North Atlantic. A little fog was noted over the waters adjacent to Florida and the Carolinas and near Chesapeake Bay.

From the vicinity of New York to the fifty-fifth meridian fog was almost entirely absent to the northward of the fortieth parallel of latitude; and there was scarcely any between the eastern part of the Grand Banks section and the western coast of Europe, except in the square 45° to 50° N., 10° to 15° W., where occurrence on 3 days was indicated. Apart from the Gulf of Mexico the most frequent occurrence was in two adjacent squares of the southwestern Grand Banks, namely, 40° to 45° N., 45° to 55° W., where 5 days of fogginess, all before the 10th, have been reported.

OCEAN GALES AND STORMS, DECEMBER 1937

Vessel	Voyage: From—	Voyage: To—	Position at time of lowest barometer: Latitude	Position at time of lowest barometer: Longitude	Gale began December	Time of lowest barometer December—	Gale ended December—	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Direction and highest force of wind	Shifts of wind near time of lowest barometer
NORTH ATLANTIC OCEAN			° ′	° ′				Inches					
Europa, Ger. S. S.	New York	Cherbourg	49 35 N.	15 40 W.	[1] 30	11 a, 1	2	29.13	WNW	WNW, 10	NE	NW, 10	
Tai Ping, Nor. M. S.	Cristobal	New York	33 43 N.	74 24 W.	2	Noon, 2	3	29.87	N	N, 7	N	N, 9	
Queen of Bermuda, Br. S. S.	Bermuda	do	36 48 N.	69 38 W.	2	3 p, 2	2	29.60	ENE	NE, 9	NE	NE, 9	ENE-NE.
Standard, Am. S. S.	Aruba	do	30 24 N.	74 48 W.	3	7 p, 2	3	29.87	N	NNW, 4	N	N, 9	None.
Maasdam, Du. S. S.	Rotterdam	do	41 54 N.	65 03 W.	3	4 p, 3	3	29.81	NE	NE, 8	NNE	NE, 9	NE-NNE.
President Harding, Am. S. S.	Cobh	do	42 06 N.	59 30 W.	4	8 p, 3	4	29.75	NNE	SSE, 6	NNE	NE, 9	SSE-N.
Exminster, Am. S. S.	Gibraltar	do	37 01 N.	65 50 W.	2	10 p, 3	5	29.47	S	NNE, 7	N	NNE, 9	S-NNE-N.
Nitro, U. S. N.	Coco Solo	Norfolk	10 54 N.	78 54 W.	4	5 p, 4	5	29.77	N	N, 5	NE	N, 6	
Lochmonar, Br. M. S.	Swansea	Curacao	[2] 48 12 N.	12 06 W.	4	4 p, 5	5	29.59	WNW	WSW, 7	W	WNW, 9	WSW-NW.
Dordrecht, Du. M. S.	New York	Liverpool	39 50 N.	63 30 W.	3	4 p, 5	5	29.55	NNE	N, 7	NNW	N, 9	None.
Amor, Du. S. S.	do	Miragoane	29 50 N.	72 12 W.	6	1 p, 6	6	29.59	S	SSW, 9	NW	SSW, 9	S-SW.
Sahale, Am. S. S.	Liverpool	New Orleans	48 00 N.	9 26 W.	6	4 p, 6	7	29.35	NW	WNW, 7	W	W, 9	SE-WNW-W.
Lahaina, Am. S. S.	Colon	Philadelphia	28 01 N.	74 39 W.	6	6 p, 6	7	29.72	SW	W, 8	NW	W, 9	SW-WNW.
Eglantier, Belg. S. S.	Maceio	Antwerp	[2] 36 00 N.	15 38 W.	8	5 a, 8	8	[3] 29.62	W	SW, 7	NW	WNW, 9	SW-NW.
Black Hawk, Am. S. S.	Antwerp	New York	49 59 N.	21 44 W.	10	1 p, 10	11	30.00	WNW	WNW, 7	NNE	NNW, 9	WNW-NNW.
Perna, Du. M. S.	Rouen	Curacao	[2] 45 55 N.	13 45 W.	13	4a, 13	13	29.54	NW	NW, 8	NW	NW, 9	W-NW.
Jean Jadot, Belg. S. S.	Antwerp	New York	50 00 N.	14 30 W.	13	4 a, 13	14	29.08	NNW	NW, 5	NNW	NW, 9	None.
Argosy, Am. S. S.	Gdynia	Baltimore	51 03 N.	42 12 W.	16	1 a, 16	17	29.07	S	E, 6	WSW	SW, 10	NE-S.
Tennessee, Dan. S. S.	Newfahrwasser	do	54 00 N.	37 30 W.	17	2 a, 17	18	29.61	SW	SW, 9	WNW	W, 9	SW-W.
Vassos, Gr. S. S.	Falmouth	Curacao	33 48 N.	38 51 W.	17	8 p, 17	17	[3] 29.66	NW	NW, 10	NW	NW, 10	
Jean Jadot, Belg. S. S.	Antwerp	New York	[2] 45 59 N.	44 08 W.	18	Noon, 18	18	29.38	S	SW, 8	NNW	SSW, 9	Veering.
Chinese Prince, Br. M. S.	Dakar	Halifax	[2] 40 17 N.	55 00 W.	19	7 p, 19	19	29.70	WSW	WSW, 9	W	WSW, 10	WSW-WNW.
Scanpenn, Am. S. S.	Copenhagen	New York	52 42 N.	37 30 W.	20	2 a, 21	22	28.69	SE	WNW, 6	WNW	W, 9	WNW-W.
Ipswich, Am. S. S.	Mobile	London	47 55 N.	27 54 W.	22	1 a, 23	23	28.96	S	SSW, 9	SW	S, 10	S-SW.
Bienville, Am. S. S.	do	Liverpool	49 45 N.	23 50 W.	22	6 a, 23	23	29.14	S	SSE, 10	SW	SSE, 10	SSE-SW.
Shickshinny, Am. S. S.	Antwerp	Charleston	36 29 N.	53 44 W.	23	11 p, 23	24	29.89	SW	SW, 9	NNW	NNW, 9	SW-NNW.
Steel Exporter, Am. S. S.	Liverpool	Portland, Maine.	48 45 N.	35 20 W.	24	Noon, 24	24	29.00	SSW	WSW, 7	SW	S, 10	SSW-WSW.
American Importer, Am. S. S.	New York	Liverpool	48 26 N.	31 21 W.	24	1 p, 24	24	29.21	S	SW, 7	W	SSW, 10	SSW-W.
Lancaster, Am. S. S.	Antwerp	Baltimore	41 07 N.	35 04 W.	24	3 p, 24	24	29.51	SW	SW, 10	Var	SW, 10	SW-var-N.
Dordrecht, Du. M. S.	Liverpool	New York	51 00 N.	24 00 W.	24	2 a, 25	25	29.55	SSW	S, 10	SW	S, 10	S-SW.
Vincent, Am. S. S.	Havre	do	39 55 N.	50 45 W.	26	9 a, 26	27	29.66	SE	SW, 10	WNW	SW, 10	SE-SW-WNW.
Steel Exporter, Am. S. S.	Liverpool	Portland, Maine.	45 18 N.	44 01 W.	26	9 p, 26	27	29.72	SE	SE, 9	WSW	SSW, 10	SE-SSW.
Vincent, Am. S. S.	Havre	New York	39 46 N.	59 49 W.	29	1 p, 29	29	29.85	SE	SW, 9	NNW	W, 10	SE-SW-WNW.
Steel Exporter, Am. S. S.	Liverpool	Portland, Maine.	43 37 N.	55 39 W.	29	6 p, 29	30	29.73	SSE	SSE, 10	WNW	SSE, 10	SSE-WNW.
Scanstates, Am. S. S.	Copenhagen	New York	55 00 N.	34 05 W.	29	2 a, 30	30	29.72	SSE	S, 7	S	SSE, 9	SSE-S.
Colytto, Du. S. S.	Antwerp	Key West	31 46 N.	54 10 W.	30	8 a, 30	30	29.90	NE	NE, 8	NE	NE, 10	E-NE.
NORTH PACIFIC OCEAN													
President McKinley, Am. S. S.	Victoria, B. C.	Yokohama	44 42 N.	155 08 E.	[1] 30	4a, 1	1	29.26	S	W, 6	NW	W, 8	S-W.
Vermont, Am. S. S.	Los Angeles	Balboa	15 00 N.	95 00 W.	2	4p, 2	3	29.68	NE	NE, 6	WNW	N, 8	W-NE.
President McKinley, Am. S. S.	Victoria, B. C.	Yokohama	39 07 N.	143 11 E.	2	4a, 3	4	29.12	E	SW, 5	WSW	WSW, 10	ESE-SW-WSW
Kyokuto Maru, Jap. M. S.	Yokohama	Los Angeles	37 18 N.	144 49 E.	3	Noon, 3	3	29.43	W	W, 8	WNW	WNW, 9	W-WNW.
Teiyo Maru, Jap. M. S.	Los Angeles	Yokohama	33 24 N.	145 12 E.	3	10a, 3	4	29.60	WNW	WNW, 8	WNW	W, 9	WSW-WNW.
President Jackson, Am. S. S.	Yokohama	Victoria, B. C.	49 03 N.	178 40 W.	4	10a, 5		28.66	E	N, 3	WNW	W, 11	WNW-NNE.
President Hoover, Am. S. S.	Honolulu	Yokohama	32 14 N.	147 54 E.	4	Noon, 5	6	29.61	W	W, 9	W	W, 9	
Neches, U. S. N.	Coco Solo	Los Angeles	16 00 N.	94 24 W.	6	4p, 6	6	29.80	N	NW, 7	NE	N, 8	NW-NE.
Toa Maru, Jap. M. S.	Los Angeles	Genzan	34 31 N.	165 25 W.	8	6a, 8	8	29.13	W	W, 7	NW	W, 9	
Fosna, Nor. M. S.	Moji	Los Angeles	36 50 N.	165 40 E	8	4a, 8	8	29.68	WNW	WNW, 8	WNW	WNW, 8	
Salawati, Du. M. S.	Manila	do	29 08 N.	168 02 W.	8	8a, 8	9	29.55	W	W, 7	NW	NNW, 9	W-NW.
President Van Buren, Am. S. S.	San Francisco	Honolulu	29 00 N.	145 06 W.	8	3p, 8	10	29.40	WSW	SW, 8	NW	SW, 9	SW-WSW
Makiki, Am. S. S.	Honolulu	San Francisco	34 43 N.	131 52 W.	8	2a, 9	9	29.21	S	SW, 10	SW	SW, 10	S-SW.
Manulani, Am. S. S.	San Francisco	Honolulu	35 06 N.	131 18 W.	8	3a, 9	11	29.15	S	SW, 8	WSW	S, 9	S-SW.
Tyndareus, Br. S. S.	Yokohama	Victoria, B. C.	41 43 N.	152 52 E.	9	4a, 9	9	29.55	NW	WNW, 6	NW	NW, 8	W-NW.
Mauna Ala, Am. S. S.	Seattle	Honolulu	36 18 N.	144 00 W.	7	10a, 9	11	28.70	ESE	SW, 8	W	W, 9	SW-WSW.
Makawao, Am. S. S.	San Francisco	do	28 57 N.	144 59 W.	8	4a, 9	10	29.33	SW	SW, 9	W	WSW, 10	None.
President Jackson, Am. S. S.	Yokohama	Victoria, B. C.	49 50 N.	140 00 W.	8	Noon, 10	10	28.37	E	NNE, 9	N	E, 11	NE-N.
Mapele, Am. S. S.	New Westminster.	Honolulu	46 12 N.	127 00 W.	10	4p, 10	10	29.01	SE	SE, 8	SE	SE, 8	
Mariposa, Am. S. S.	Los Angeles	do	30 14 N.	133 33 W.	10	4p, 10	10	29.61	SW	SW, 9	SW	SW, 9	None.
Takaoka Maru, Jap. S. S.	Yokohama	do	23 55 N.	163 04 W.	11	1a, 11	11	29.63		S, 8		S, 8	
Chichibu Maru, Jap. M. S.	Honolulu	Yokohama	28 57 N.	176 23 W.	10	2p, 10	13	28.94	SE	WSW, 9	NNW	WNW, 10	SSW-NW.
Corneville, Nor. M. S.	Hong Kong	Los Angeles	36 24 N.	169 18 W.	10	4a, 11	11	28.57	ENE	N, 11	NW	N, 11	ENE-N-NW.
Fujisan Maru, Jap. M. S.	Yokohama	San Pedro	42 00 N.	153 00 W.	11	2a, 12	12	28.62	SSE	SSW, 9	SW	S, 9	SSE-SW.
Hakonesan Maru, Jap. M. S.	do	Los Angeles	[2] 44 24 N.	147 39 W.	11	5a, 12	12	28.92	SE	SSW, 8	SSW	SSW, 9	SE-SW.
Empress of Russia, Br. S. S.	Victoria, B. C.	Yokohama	[2] 52 06 N.	157 25 W.	13	Mdt, 14	14	28.87	S	ENE, 4	SW	W, 8	S-ENE.
California, Am. S. S.	Vladivostok	San Francisco	43 10 N.	146 57 E.	14	Mdt, 14	15	29.07	NW	NW, 8	N	NW, 9	NW-N.
President Jefferson, Am. S. S.	Yokohama	Victoria, B. C.	39 50 N.	149 32 E.	13	8a, 15	15	28.98	NW	SW, 8	SE	WNW, 9	W-SW-SE.
Tyndareus, Br. S. S.	do	do	50 06 N.	158 55 W.	14	8p, 14	15	28.78	SSW	SW, 4	SW	WSW, 8	ESE-SW.
Asosan Maru, Jap. M. S.	do	San Francisco	44 42 N.	165 18 E.	19	11p, 18	19	29.75		W, 6		NW, 8	
California, Am. S. S.	Vladivostok	do	44 37 N.	172 08 E.	18	2p, 19	19	29.69	NW	NNW, 8	N	NW, 9	
Olympia Maru, Jap. M. S.	Dairen	Los Angeles	36 29 N.	147 00 E.	19	Mdt. 19	20	29.37	S	W, 5	NNW	S, 8	S-NNW.
Empress of Russia, Br. S. S.	Victoria, B. C.	Yokohama	44 08 N.	155 38 E.	20	10a, 20	20	29.03	SSE	SE, 10	WSW	SE, 10	SE-W.
Arizonan, Am. S. S.	Los Angeles	Balboa	14 49 N.	95 31 W.	20	5a, 20	20	29.91	NE	NE, 6	N	N, 8	ENE-N.
Talthybius, Am. S. S.	Vancouver, B. C.	Yokohama	45 07 N.	150 08 E.	20	2p, 20	20	29.29	SE	SSE, 9	SW	SE, 10	SE-W.
Olympia Maru, Jap. M. S.	Dairen	Los Angeles	37 56 N.	163 19 E.	23	8a, 23	24	28.94	SE	WNW, 8	NW	WNW, 10	W-WNW-NW.
Aorangi, Br. S. S.	Victoria, B. C.	Honolulu	46 26 N.	128 51 W.	23	8p, 23	24	29.40	WNW	WNW, 8	NW	NW, 9	WSW-NW.
Hikawa Maru, Jap. M. S.	Yokohama	Vancouver, B. C.	49 49 N.	157 30 W.	25	Mdt, 25	26	29.31	ENE	ENE, 8	NNE	ENE, 8	None.
California, Am. S. S.	Vladivostok	San Francisco	43 26 N.	143 00 W.	27	10a, 27	27	29.02	SW	SW, 7	WSW	SW, 8	SW-WSW.
Coloradan, Am. S. S.	San Francisco	Portland, Oreg.	46 54 N.	125 24 W.	27	4a, 28	28	29.64	SSW	S, 10	SSE	S, 11	S-SSE.
Makiki, Am. S. S.	Seattle	Honolulu	44 12 N.	132 06 W.	27	3p, 27	29	29.48	SW	SW, 6	WSW	SW, 10	None.

[1] November. [2] Position approximate. [3] Barometer uncorrected.

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NORTH PACIFIC OCEAN, DECEMBER 1937

By WILLIS E. HURD

Atmospheric pressure.—Numerous deep cyclones were charted over northern and central waters of the North Pacific during December 1937. From the 4th to the 16th, and on a few later days, pressures below 29 inches were read on ships at various times along the entire stretch of the northern routes. At Midway Island, on the 11th, the barometer fell to 29.04, and on the 10th and 11th still lower readings were made on shipboard nearby.

The average pressures in the Aleutian region were higher than the normal of the month, but the excess in the average for December of this year was due to the high readings of the 20th to 23d, with a maximum of 31 inches or higher at St. Paul and Kodiak on the 21st. As an example of the excessive pressure fluctuations of the month in high latitudes, the instance of Kodiak, with the lowest reading of 28.58 on the 18th and the highest reading of 31.00, on the 21st, may be cited.

In consequence of the greatly extended sphere of cyclonic activity, the regions of average high pressure were abnormally restricted into two small areas, one lying off the coast of California and the other extending from the east coast of China seaward across the Nansei and Ogasawara Islands.

The extreme pressure readings recorded were 31.10, at St. Paul on the 21st, and 28.37, on the steamship *President Jackson*, near 50° N., 140° W., on the 10th.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, North Pacific Ocean, December 1937, at selected stations*

Stations	Average pressure	Departure from normal	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Point Barrow	30.32	+0.29	31.06	8, 9	29.50	19
Dutch Harbor	29.59	+.03	30.92	21	28.54	18
St. Paul	29.79	+.21	31.10	21	28.92	18
Kodiak	29.64	+.08	31.00	21	28.58	14
Juneau	29.88	+.09	30.78	21	29.19	14
Tatoosh Island	29.97	+.01	30.67	20	28.94	10
San Francisco	30.07	−.05	30.35	28	29.62	9
Mazatlan	29.92	−.01	29.98	20–22, 24	29.82	15
Honolulu	29.96	−.05	30.19	14	29.70	
Midway Island	29.96	−.05	30.24	26	29.04	11
Guam	29.84	−.03	29.92	14, 15	29.77	6, 22, 26
Manila	29.84	−.02	29.94	14	29.68	7
Hong Kong	30.03	−.06	30.14	5	29.92	9, 23
Naha	30.07	+.09	30.18	4, 5, 12	29.89	31
Titijima	30.02	+.02	30.21	16	29.83	25

NOTE.—Data based on 1 daily observation only, except those for Juneau, Tatoosh Island, San Francisco, and Honolulu, which are based on 2 observations. Departures are computed from best available normals related to time of observation.

Extratropical cyclones and gales.—An unusual number of deep cyclones, some of great extent and duration, occurred on the North Pacific during December. While the maximum wind reported did not exceed force 11 in any of these disturbances, gales were of practically daily occurrence on the ocean outside the tropics, and the month may well be considered a stormy one. Heavy weather conditions resulting from extratropical disturbances penetrated into low latitudes on several days, and winds of whole gale force occurred on the 10th accompanied by low pressures in two localities south of the thirtieth parallel.

The earliest storm of importance in the month was centered near the southeast coast of Honshu late on the 2d and early on the 3d. At or near Yokohama on the 3d, according to the report of the Japanese motorship *Tatsuta Maru*, the barometer fell to 29.33, with a fresh west gale. To the eastward on the 3d the American steamer *President McKinley* encountered a west-southwest gale of force 10, barometer down to 29.12. In Yokohama harbor on the 4th this ship reported a whole westerly gale. The storm field spread during the 3d and 4th, and some fresh to strong gales connected with it were experienced as far to the eastward as 170° E., between 30° and 35° N.

By the 4th several deep centers lay over northern waters and were followed by similar conditions until the 18th, after which there was an abatement in the general depth and severity of the storms, following the sudden appearance of a powerful anticyclone over northern waters.

On the 4th to 6th the American steamer *President Jackson*, Yokohama to Victoria, passed through a storm area south of the Aleutians, with barometer depressed to 28.66 inches on the 5th near 49° N., 179° W., and attended by intermittent gales which reached their greatest intensity, force 11, early on the 6th.

On December 10 a storm, with little known antecedent history, appeared central in the near vicinity of Midway Island, with pressures on two ships, one closely north of the island and the other to the eastward, reading 28.94, both accompanied by whole gales. At Midway, on the early morning of the 11th, the extraordinarily low reading for the station of 29.04 inches was recorded. At 4 a. m. of the 11th the Norwegian motorship *Corneville*, after experiencing gales for several hours northeast of Midway, ran into a north gale of force 11, barometer 28.57, in 36°24′ N., 169°18′ W. The storm thereafter, with rapidly decreasing energy and increasing speed, moved northward and lay over the eastern Aleutians on the 12th and 13th.

On December 8, while most of the eastern half of the ocean was a scene of unsettled weather and low barometer, a storm center, with lowest pressure about 28.70, appeared near 40° N., 160°–165° W. It moved northeastward, during its passage coalescing with another center from the Aleutians, and on the 10th was central near 50° N., 140° W., where the steamer *President Jackson*, shortly after encountering a second force 11 gale of the month, had a barometer of 28.37 inches. During the 9th and 10th, while strong southerly winds occurred along the upper coast of the United States, the gale area of the great disturbance, as shown by vessel reports, extended as far south, at least, as the twenty-eighth parallel, and from about longitude 155° W. eastward almost to the Washington and Oregon coasts. Near 36° N., 144° W., pressure was 29.70 on the 9th, attended by strong gales, while as far south in latitude as 29° N., 145° W., the American steamer *Makawao* had a barometer depressed to 29.33 inches, with strong to whole westerly gales. By the 11th the storm had moved northward and its gale field had retreated from the California-Hawaiian routes.

From the 12th to 18th scattered gales of force 8–9 occurred on various parts of the ocean, and may best be located by reference to the table of gales.

On the 19th and 20th a storm passed up the east Japanese coast and entered the Sea of Okhotsk. During these days strong to whole gales swept the western waters of the northern steamship routes, while central pressures fell to approximately 29 inches.

From the 23d to 28th stormy weather prevailed in coastal Washington and neighboring waters. A small

depression southwest of Vancouver Island on the 23d and 24th resulted in disturbed conditions prior to its passage inland over British Columbia. The British steamer *Aorangi*, outward bound from Victoria, encountered fresh westerly gales late on the 23d, increasing to force 9 early on the 24th. The ship's lowest pressure, 29.40, was read on the 23d near 46½° N., 129° W.

Closely following upon the heels of this LOW, a further disturbance pressed in upon the Washington coast from the westward. From the 27th to 29th strong winds to gales were experienced in connection with it to the eastward of 150° W., and to the northward of the fortieth parallel. On the morning of the 28th the storm center was near 52° N., 140° W., with lowest observed pressure 28.62; and at p. m. observation the center had moved eastward to about 132° W., with barometer about 28.70. Early on the morning of the 28th the American steamship *Coloradan*, bound up the coast to Portland, after steaming in southerly gales since the previous noon, experienced a south gale of force 11 in 46°54′ N., 125°24′ W. Gales of decreasing force continued until the ship entered the Columbia River. The storm center after the 28th moved toward the Gulf of Alaska, but continued to cause gales on the 29th far to the southward along the eastern extremity of the northern steamer route.

The following wind velocities, speed in miles per hour with the corresponding direction, were recorded for 5-minute periods at the Weather Bureau Station at North Head, Wash., during the 24th to 28th: 24th, 50 west; 25th, 61 south; 26th, 54 southwest; 27th, 64 south; 28th, 70 south.

Typhoon in the Far East.—One typhoon occurred in the Far East this month. An account of it, prepared by the Reverend Bernard F. Doucette, S. J., of the Philippine Weather Bureau, is subjoined.

Gales on and near the Gulf of Tehuantepec.—Strong northerly winds of the Tehuantepecer type occurred as follows: Of force 7 on the 4th, 11th, 12th, and 27th; and of force 8 on the 2d, 3d, 6th, and 20th. The U. S. S. *Neches*, Coco Solo to San Pedro, in addition to the Tehuantepecer of the 6th, experienced a northeast Papagayo of force 7 off the Costa Rican coast on the 4th.

Fog.—Fog was infrequent this month on the North Pacific. It was reported on 5 days along the middle section of the northern routes; on 5 days several hours out from the coast of the United States; and on 1 day near the mouth of the Columbia River. Off the coast of southern and Lower California it occurred on 3 days, and northwest of the Revillagigedo Islands on 1 day.

TYPHOON OVER THE FAR EAST, DECEMBER 1937

Rev. BERNARD F. DOUCETTE, S. J.

[Weather Bureau, Manila, P. I.]

Typhoon, December 2–14, 1937.—A low pressure area appeared over the Western Caroline Islands on November 30, but a definite center did not form until December 2, when a depression was central about 200 miles east-southeast of Yap. It moved rather rapidly in a northwesterly direction, inclining somewhat to the west-northwest as it approached the one hundred and thirty-fifth meridian. On December 3 it changed to the west-southwest, intensifying as it proceeded. The next morning found it about 300 miles east of Surigao Strait, from which position it moved west by north, crossing southern Samar Island between Borongan and Guiuan. On December 5 it moved across the Visayan Islands, crossing the southern part of Masbate Island and passing close to and north of Panay Island. At 6 a. m. December 6 its center was located between Tablas and Mindoro Islands. It now began an irregular course, moving slowly and weakening. First there was an inclination to the south for about 20 miles, then during the forenoon of December 7 a shift to the east, bringing the center to the northwestern part of Panay Island, and finally a change to the southwest, which carried the disturbance to the northern part of the Sulu Sea (December 8). These facts briefly indicate its irregular course. Now, as a weak low pressure area it moved along a west-northwest course into and across the China Sea, where it intensified into a typhoon. The steamship *President Polk*, en route from Manila to Singapore, came under its influence after it again became a typhoon, central near latitude 12° N., longitude 115° E. The typhoon now continued along a west-northwest course for a short period, moving in a northerly direction December 13 and disappearing over the region of the Paracel Islands and Reefs, December 14.

This storm followed a course over the Visayan Islands similar to the typhoon of November 15–23, 1937. However, only four deaths resulted from this typhoon according to the newspaper reports, two from Masbate and two from Mindoro being the only casualties coming to the notice of the public.

On December 11 and 12 an increase in the strength of the northeast monsoon current caused the intensification of the low pressure area over the China Sea as mentioned above. The steamship *President Polk* reported on December 12, 2 p. m. Manila time, 749.7 mm (29.516 in.) with south-southeast winds force 8, at latitude 12.20° N., longitude 115.30° E.

Over the Visayan Islands the significant barometric minima are listed as follows: Borongan had 737.22 mm (29.025 in.) at 4 p. m. December 4; Guiuan, 1 hour before, had a minimum value of 745.79 mm (29.362 in.); Tacloban's minimum value occurred at 7:30 p. m. of the same day, and was 744.70 mm (29.319 in.); December 5 at 3 p. m. 747.7 mm (29.437 in.) was recorded at Masbate; December 6, at 4:25 a. m., Odiongan had a value of 745.34 mm (29.344 in.), and Cuyo, 2 days later, reported 748.65 mm (29.474 in.) as the minimum (December 8, 10 a. m.). The strongest winds reported were west winds, force 11, at Tacloban. During the course of the storm over the Visayan Islands, after crossing Samar, the strongest winds reported were force 7.

SEA-SURFACE TEMPERATURE SUMMARY FOR A PORTION OF THE NORTH ATLANTIC OCEAN NEAR TO AND EAST OF THE VIRGINIA-NORTH CAROLINA CAPES

By GILES SLOCUM

The area embraced in this summary comprises eleven 1° squares, namely:

From 35° N. to 36° N., 69° W. to 74° W.
From 36° N. to 37° N., 69° W. to 73° W.
From 37° N. to 38° N., 69° W. to 71° W.

This area includes a portion of the axis of the Gulf Stream, but lies south and east of its shoreward portions, thus excluding nearly all of the area alternately occupied by the Gulf Stream and by the cold waters of the con-

tinental slope.[4] The area here summarized includes, in its southern and eastern portions, however, waters oceanward from, and slightly cooler than, the Gulf Stream.

The table shows monthly mean sea-surface temperatures, compiled to tenths of a Fahrenheit degree, except for 1918, when the observations were few in number. As indicated in the table, no data are available for July 1918. The interpolated temperature, 78.3°, has been used for this month in computing averages.

This is the ninth of a series of temperature-history tabulations of this character showing sea-surface temperatures for small areas in American waters. The first of the series appeared in the November 1934 issue of the MONTHLY WEATHER REVIEW and the last previous tabulation appeared in the September 1936 issue.

[4] Called the "Slope Water" in: Church, P. E., Temperatures of the Western North Atlantic from Thermograph records, Association D'Oceanographie Physique Publication Scientifique No. 4. 1937. Fig. 2.

Monthly and annual mean sea-surface temperatures in the warm waters east of the Virginia and North Carolina capes, 1912 to 1931, inclusive

Stations														
Year	Total number of observations for the year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912	491-	67.3	64.8	64.8	68.4	73.1	75.0	79.4	79.9	78.4	75.4	71.5	69.9	72.3
1913	503	69.8	66.6	67.1	69.6	70.9	74.5	77.8	78.6	78.1	74.5	72.2	69.5	72.4
1914	395	65.5	66.2	65.0	67.9	69.8	74.9	78.5	79.8	77.8	74.5	73.0	69.8	71.9
1915	440	67.9	66.9	65.5	67.4	71.9	73.8	78.8	82.0	79.9	75.7	73.5	68.1	72.6
1916	275	66.9	67.0	66.3	66.0	69.4	74.1	76.0	79.7	78.2	73.8	71.9	69.6	71.6
1917	106	65.3	63.4	64.7	69.7	69.4	74.0	78.9	78.3	76.7	75.3	67.7	68.6	71.0
1918	40	62	65	69	66	72	74	(1)	80	80	74	74	72	[2] 72.1
1919	156	67.0	62.2	66.8	64.4	70.9	73.3	77.5	79.4	78.4	77.4	71.9	69.4	71.6
1920	286	66.8	63.9	68.4	66.3	67.8	73.7	77.2	79.8	78.6	75.4	73.3	69.8	71.8
1921	453	67.2	65.9	68.5	70.5	70.6	76.0	78.1	78.9	79.7	76.2	73.2	69.9	72.9
1922	430	68.2	66.3	66.3	67.8	69.7	74.6	78.9	79.0	77.6	76.6	72.7	70.6	72.4
1923	601	66.5	65.8	68.5	69.6	72.7	76.3	78.4	79.8	79.0	75.7	72.1	69.9	72.9
1924	678	69.1	65.5	67.1	67.8	71.7	76.0	79.6	79.9	78.6	75.0	71.9	69.3	72.6
1925	683	66.1	67.6	67.9	68.9	72.8	76.8	79.0	79.4	77.3	75.6	71.5	68.9	72.6
1926	785	65.9	66.0	64.8	69.1	72.8	75.8	78.9	81.0	79.2	76.9	72.3	69.6	72.7
1927	919	67.4	67.0	68.2	69.2	72.0	75.5	78.5	79.5	78.7	75.8	73.5	70.3	73.0
1928	909	68.0	65.2	66.5	68.6	70.5	75.2	79.1	80.3	79.0	77.6	72.9	69.7	72.7
1929	900	67.6	65.6	68.7	71.3	72.8	76.4	79.0	79.4	78.9	75.6	74.1	71.9	73.4
1930	871	69.2	69.0	68.6	69.6	73.2	75.3	79.6	79.6	79.5	74.9	73.1	69.5	73.4
1931	769	67.1	65.8	64.4	65.4	70.6	74.6	79.7	80.9	80.1	75.8	74.2	71.7	72.5
Number of years' record		20	20	20	20	20	20	19	20	20	20	20	20	20
Mean (1912-31)[3]		67.1	65.8	66.9	68.2	71.2	75.0	78.6	79.8	78.7	75.6	72.5	69.9	[2] 72.4

[1] No data.
[2] Interpolated values are used for missing months.
[3] All monthly values were carried to 1 decimal place for these means, which, therefore, are not exact means of figures given here.

CLIMATOLOGICAL TABLES

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

TABLE 1.—*Condensed climatological summary of temperature and precipitation by sections, December 1937*

[For description of tables and charts, see REVIEW, January, p. 29]

Section	Temperature								Precipitation					
	Section average	Departure from the normal	Monthly extremes						Section average	Departure from the normal	Greatest monthly		Least monthly	
			Station	Highest	Date	Station	Lowest	Date			Station	Amount	Station	Amount
	° F.	° F.		° F.			° F.		In.	In.		In.		In.
Alabama	47.0	−0.5	4 stations	76	[1]14	2 stations	4	[1]9	2.72	−2.69	Belgreen	5.01	Marion	0.96
Arizona	46.4	+2.0	Wellton	82	29	Springerville	4	20	1.18	−.04	Bright Angel	3.71	Pacinimo	.19
Arkansas	42.2	−.5	Magnolia	78	16	Lead Hill	0	10	4.62	+.33	Highland	11.35	Ozark	2.49
California	48.3	+2.7	Palm Springs	90	7	Boca	−12	24	5.42	+1.68	Scales	22.93	El Centro	.03
Colorado	27.8	+2.3	Pueblo	76	11	2 stations	−22	[1]20	1.11	+.20	Crested Butte	2.92	Del Norte	.02
Florida	57.5	−2.2	2 stations	88	[1]24	Mason	14	7	1.26	−1.50	Mason	2.95	Davie	.17
Georgia	46.5	−1.2	do	78	[1]15	Blairsville	−3	11	2.03	−2.25	Gillsville	3.78	Brunswick	.69
Idaho	30.4	+4.3	Grand View	64	11	Deadwood	−16	31	3.30	+1.25	Roland	9.75	Bruneau	.52
Illinois	28.5	−1.9	Cairo	62	16	Freeport	−4	23	2.10	−.15	Edwardsville	4.35	Walnut	.73
Indiana	29.4	−2.7	Shoals	60	16	Wabash	−2	12	2.74	−.11	Greensburg	4.63	La Porte	1.00
Iowa	22.8	−1.2	2 stations	50	29	3 stations	−11	[1]9	.74	−.45	Keokuk	1.90	Onawa	.06
Kansas	31.8	−1.1	St. Francis	73	11	Burr Oak	−8	10	.53	−.32	Fredonia	1.58	Plains	.04
Kentucky	35.5	−2.2	Pippapass	68	16	2 stations	0	9	2.94	−1.00	Russellville	4.60	Farmers	1.25
Louisiana	52.3	−.1	Delta Farms	80	31	Tallulah	14	11	4.34	−1.02	Plain Dealing	9.15	Lake Charles	2.22
Maryland-Delaware	34.7	−1.0	La Plata, Md	74	18	Oakland, Md	−12	12	1.28	−2.04	Oakland, Md	3.24	Keedysville, Md	.51
Michigan	22.9	−2.8	South Haven	49	31	2 stations	−21	[1]13	1.66	−.37	Deer Park	6.75	Mio	.31
Minnesota	12.9	−2.6	2 stations	51	2	Pokegama Falls	−30	25	.68	−.10	Pigeon River Bridge	2.51	Alexandria	.06
Mississippi	47.5	−.7	Rolling Fork	80	14	Holly Springs	8	9	3.92	−1.40	Rolling Fork	7.48	Forest	1.90
Missouri	32.0	−2.0	Garber	66	30	5 stations	−2	[1]8	2.24	+.07	Parma	4.70	King City	.53
Montana	23.2	+.2	Grass Range	60	11	Summit	−38	9	1.16	+.27	Trout Creek (near)	6.01	Lustre (near)	.01
Nebraska	27.0	+.2	4 stations	66	[1]11	Gordon	−24	24	.29	−.40	Potter	1.19	3 stations	.00
Nevada	35.9	+5.0	2 stations	74	10	Montello	−12	24	1.48	+.48	Lewers Ranch	9.22	Las Vegas	.04
New England	25.4	−1.1	East Wareham, Mass.	57	19	Fort Kent, Maine	−24	31	2.96	−.37	Durham, N. H	5.73	Bennington, Vt	.99
New Jersey	33.2	−.5	Bridgeton	70	18	Runyon	0	[1]11	1.75	−1.90	Sussex	2.83	Bridgeton	.86
New Mexico	35.6	+1.7	2 stations	80	[1]12	Eagle Nest	−14	21	.56	−.12	Cloudcroft	2.12	4 stations	.00
New York	26.1	−.6	Flushing	63	18	Lawrenceville	−19	31	2.51	−.40	Jamestown	5.06	Burdett	1.22
North Carolina	41.1	−1.5	Newbern	77	18	Mount Mitchell	−13	7	2.36	−1.48	Tapoco	4.70	Manteo	1.22
North Dakota	11.4	−1.2	Carson	51	2	Marmarth	−33	10	.54	+.04	Fullerton	1.93	Mayville	.07
Ohio	28.9	−2.7	Ironton	62	31	McArthur	−6	12	2.91	+.16	Hillsboro	5.01	Holgate	1.14
Oklahoma	38.7	−1.1	Kenton	77	11	Kenton	1	15	1.54	−.15	Marietta	5.23	2 stations	.10
Oregon	37.2	+3.8	Port Orford	76	10	Chemult	0	25	5.49	+1.66	Valsetz	35.96	Grizzly	.55
Pennsylvania	29.7	−1.5	Neshaminy Falls	66	18	Somerset	−14	13	2.45	−.66	Westford	5.72	Holtwood	.70
South Carolina	44.5	−2.2	Walterboro	79	16	Caesars Head	2	7	2.56	−1.04	Caesars Head	4.61	Beauforte (near)	.87
South Dakota	20.0	−.8	Hot Springs	65	11	Camp Crook	−33	9	.56	+.01	Dumont	1.72	Reva (near)	.01
Tennessee	39.2	−1.5	Milan	72	17	Lewisburg	−6	9	3.65	−.93	Cedar Hill	5.41	Covington	2.03
Texas	48.5	−.4	2 stations	87	12	Dalhart	10	15	4.15	+1.87	George West	11.53	Perryton	.08
Utah	32.6	+6.0	do	65	[1]9	Ibapah	−10	20	1.47	+.37	Great Basin Experiment Station.	3.89	Escalante	.18
Virginia	37.1	−.9	do	75	18	Emory	−3	11	1.32	−1.77	Pennington Gap	3.20	Big Meadows	.20
Washington	35.9	+3.3	Landsburg	72	28	Stockdill Ranch	−10	23	7.36	+1.61	Cougar (near)	27.41	Mansfield (near)	.83
West Virginia	32.2	−2.3	2 stations	66	17	2 stations	−9	12	2.66	−.68	Sutton	5.15	White Sulphur Springs	.35
Wisconsin	18.1	−2.3	do	45	31	Solon Springs	−22	23	.84	−.47	Waukesha	2.10	Laona	.27
Wyoming	23.6	+1.9	Yoder	69	11	West Yellowstone	−33	8	1.14	+.39	Bechler River	5.43	Powell	.04
Alaska (November)	21.2	+7.4	Wrangel	63	5	Allakakett	−36	21	2.31	−.42	Little Port Walter	25.21	Richardson	.12
Hawaii	71.2	+1.0	Kannapali	90	20	Kanalohuluhulu	43	18	8.93	−.43	Puohakamoa No. 2	40.00	Mahuokna	.15
Puerto Rico	74.6	+.3	Dos Bocas	95	13	3 stations	55	[1]4	2.73	−1.91	La Mina (El Yunque).	12.37	Sabana Grande	.05

[1] Other dates also.

TABLE 2.—*Climatological data for Weather Bureau stations, December 1937*

[Compiled by Annie E. Small, by official authority U. S. Weather Bureau]

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01 inch or more	Wind: Average hourly velocity	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F		°F	°F.		°F	°F.	°F.	°F.	%	In.	In.		Miles								0–10	In.	In.
New England							28.8	−0.7										74	2.95	−0.5										5.5		
Eastport	76	67	85	29.95	30.04	+0.06	25.4	−0.9	49	7	32	−4	31	19	32	24	20	79	1.51	−2.3	12	12.1	nw.	39	e.	7	8	7	16	6.5	7.3	3.2
Greenville, Maine	1,070	6	40	28.94	30.07	----	16.2	−2.4	40	7	25	−18	28	8	38	14	12	----	2.33	−.8	11	5.7	nw.	29	----	14	10	8	13	----	16.0	12.0
Portland, Maine	103	82	117	29.95	30.08	+.05	27.0	−.6	46	7	33	5	31	21	23	23	17	69	4.18	+.2	10	8.7	n.	32	ne.	7	15	7	9	4.2	10.5	3.8
Concord	289	60	----	29.75	30.08	+.02	24.7	−2.1	42	5	33	0	31	17	25	----	----	----	3.56	+.4	10	----	nw.	----	----	----	13	8	10	5.2	9.7	3.7
Burlington	403	11	48	29.62	30.09	+.04	21.8	−2.6	40	22	29	−8	31	14	30	19	16	82	2.29	+.4	10	9.6	s.	32	s.	28	7	8	16	6.5	15.6	8.0
Northfield	876	12	60	29.10	30.09	+.04	18.9	−1.5	41	22	28	−6	21	10	31	16	14	85	2.35	−.1	10	6.6	s.	21	n.	29	9	10	12	6.0	15.9	8.8
Boston [1]	29	33	62	30.04	30.07	+.02	31.2	−1.3	50	7	37	16	14	25	23	27	22	71	5.09	+1.6	9	10.7	nw.	29	w.	23	11	10	10	5.2	4.6	1.0
Nantucket	12	14	90	30.05	30.06	+.01	36.4	+.6	55	18	42	21	13	31	24	33	29	74	2.76	−1.0	9	14.9	nw.	47	ne.	3	8	7	16	6.5	.4	.0
Block Island	26	11	46	30.05	30.08	+.02	35.3	−.7	55	18	40	21	14	30	17	33	28	74	2.22	−1.6	9	17.7	nw.	40	nw.	14	12	11	8	5.0	T	.0
Providence	159	215	251	29.91	30.09	+.03	31.8	+.2	49	22	38	15	14	26	23	28	22	69	3.22	−.2	10	10.7	nw.	38	nw.	23	13	9	9	4.8	2.9	T
Hartford	159	66	100	29.92	30.10	+.03	31.0	+1.2	48	22	37	15	14	25	20	----	----	----	2.33	−1.6	8	7.7	n.	25	nw.	23	12	10	9	4.9	2.1	1.0
New Haven	106	74	153	30.00	30.12	+.05	33.0	+.5	47	22	39	17	13	27	19	28	20	59	2.95	−1.1	9	9.0	n.	26	nw.	14	12	6	13	5.5	1.7	T
Middle Atlantic States							35.6	0.0										68	1.43	−1.9										6.1		
Albany	97	97	112	30.01	30.12	+.04	28.8	+.3	46	22	35	7	31	22	22	25	19	69	2.05	−.6	13	6.9	nw.	18	s.	16	9	9	13	5.9	5.1	.6
Binghamton	871	57	79	29.15	30.11	+.02	28.8	+.6	49	18	35	5	11	23	27	----	----	----	2.00	−.3	10	6.6	nw.	22	nw.	26	5	6	20	7.8	4.1	.0
New York	314	415	454	29.78	30.13	+.04	35.4	+.4	62	18	42	18	13	29	24	30	22	60	1.95	−1.7	8	15.1	nw.	44	w.	7	10	7	14	5.8	.4	.0
Harrisburg	374	94	104	29.74	30.16	+.04	32.8	+.1	56	18	38	15	12	27	21	29	22	66	1.52	−1.5	10	7.1	w.	25	sw.	22	9	9	13	6.1	2.3	.0
Philadelphia	114	174	367	30.02	30.16	+.05	36.0	−.3	64	18	42	18	12	30	22	31	24	63	1.05	−2.4	6	11.9	nw.	27	w.	7	8	8	15	5.8	T	.0
Reading	323	283	306	29.78	30.15	----	34.5	+2.3	62	18	40	17	12	28	21	30	23	66	1.34	−2.2	11	10.7	nw.	39	w.	7	8	7	16	6.5	4.1	.0
Scranton	805	72	104	29.23	30.13	+.03	30.2	−.5	54	18	36	8	11	24	25	26	20	66	1.95	−1.1	9	6.3	sw.	24	nw.	18	7	5	19	6.8	3.8	T
Atlantic City	52	37	172	30.08	30.14	+.04	37.2	+.8	58	18	44	16	12	31	20	33	27	68	1.28	−2.7	9	14.1	w.	36	w.	7	9	8	14	6.3	.5	.0
Sandy Hook	22	10	57	30.10	30.12	----	35.8	+.6	61	18	40	20	13	32	21	32	26	69	1.26	−2.8	7	15.1	w.	41	w.	7	10	6	15	5.6	T	.0
Trenton	190	88	106	29.93	30.14	----	34.2	−.2	65	18	40	16	14	28	26	30	23	65	1.14	−2.2	7	8.4	nw.	23	w.	7	9	5	17	6.3	T	.0
Baltimore	123	100	215	30.02	30.16	+.03	38.0	+.8	69	18	44	20	12	32	25	32	24	59	.95	−2.4	7	9.9	sw.	35	w.	7	8	10	13	5.6	.8	.0
Washington	112	62	85	30.03	30.16	+.03	37.0	+.4	72	18	44	17	12	30	30	32	24	63	.71	−2.6	6	6.7	nw.	29	nw.	7	10	9	12	5.8	T	.0
Cape Henry	18	8	54	30.13	30.15	----	41.1	−2.6	73	18	47	24	12	35	29	38	33	74	1.79	−1.6	9	12.4	n.	38	n.	3	9	10	12	5.7	.3	.0
Lynchburg	686	148	184	29.42	30.18	+.04	39.2	−.3	68	18	48	13	12	31	30	34	28	69	1.03	−2.2	7	6.8	sw.	26	nw.	7	9	10	12	5.7	1.9	.0
Norfolk	91	80	125	30.07	30.17	+.04	42.1	−1.0	70	18	48	24	7	36	29	37	32	72	1.87	−1.5	9	9.5	n.	30	n.	2	5	13	13	6.2	.1	.0
Richmond	144	11	52	30.02	30.18	+.04	40.0	+.2	70	16	48	20	12	32	32	34	28	70	.90	−2.4	8	8.1	ne.	27	w.	18	10	10	11	5.7	1.2	.0
Wytheville	2,304	49	55	27.70	30.17	+.02	34.4	−.9	59	18	42	7	7	27	30	31	28	81	1.50	−1.4	14	7.5	w.	24	w.	22	11	5	15	6.2	2.9	.0
South Atlantic States							45.7	−1.6										75	1.95	−1.4										5.3		
Asheville	2,253	89	104	27.77	30.21	+.05	38.4	+.6	68	16	48	5	7	29	33	34	29	75	1.57	−1.6	9	7.6	n.	25	se.	17	9	5	17	6.2	.7	.0
Charlotte	779	63	86	29.32	30.18	+.02	42.0	−1.0	66	16	50	14	7	34	29	37	32	70	2.79	−1.1	10	7.1	ne.	21	sw.	18	9	8	14	6.1	T	.0
Greensboro [1]	886	6	56	29.20	30.18	----	38.6	----	65	16	48	14	7	30	34	32	30	80	1.28	----	9	7.5	sw.	24	sw.	12	7	12	12	6.0	T	.0
Hatteras	11	5	50	30.14	30.15	+.02	46.0	−4.1	65	18	52	29	7	40	24	42	40	83	3.55	−.7	12	13.8	n.	40	n.	2	10	8	13	5.8	.0	.0
Raleigh	376	103	140	29.75	30.17	+.02	42.6	−.4	71	16	50	18	7	35	32	38	33	74	2.38	−1.2	11	8.3	n.	21	n.	3	11	12	8	5.2	2.0	.0
Wilmington	72	73	107	30.10	30.18	+.03	46.2	−2.9	72	17	55	22	7	38	31	40	35	73	2.14	−.6	10	8.0	n.	29	sw.	18	12	9	10	4.8	T	.0
Charleston	48	11	92	30.13	30.18	+.03	48.4	−3.3	68	18	56	18	7	41	24	43	38	75	1.48	−1.2	5	8.7	n.	28	ne.	2	12	8	11	5.4	.0	.0
Columbia, S. C	347	70	91	29.80	30.20	+.04	45.4	−1.8	71	16	55	15	7	36	29	39	33	68	2.01	−1.0	6	7.4	ne.	21	sw.	18	13	7	11	5.0	.0	.0
Greenville, S. C	1,039	139	----	----	----	----	42.5	+.3	65	17	51	11	7	34	25	----	----	----	1.85	−3.0	5	----	ne.	----	----	----	11	2	18	----	.0	.0
Augusta	182	62	77	29.98	30.18	+.02	46.4	−1.7	71	16	57	15	7	36	32	40	35	71	1.99	−1.3	5	5.4	nw.	18	nw.	6	13	9	9	4.8	T	.0
Savannah	65	73	152	30.11	30.18	+.03	51.0	−1.4	73	25	61	18	7	41	29	43	39	74	1.09	−1.8	5	9.3	n.	28	nw.	6	15	7	9	4.6	.0	.0
Jacksonville	43	86	110	30.12	30.17	+.03	54.2	−2.1	79	17	64	21	7	45	28	47	44	81	.64	−2.4	8	7.6	ne.	21	w.	6	14	9	8	4.0	.0	.0
Florida Peninsula							63.6	−1.7										79	0.85	−1.2										4.5		
Key West	21	10	64	30.06	30.08	.00	68.6	−1.7	83	18	73	48	8	64	19	63	61	84	.82	−.8	8	10.5	ne.	34	nw.	6	11	12	8	4.7	.0	.0
Miami	25	124	168	30.07	30.10	−.01	67.0	−1.0	79	18	73	40	7	61	27	61	58	76	.40	−1.3	8	9.9	n.	24	w.	6	10	11	10	5.2	.0	.0
Tampa	35	88	197	30.09	30.13	+.01	59.8	−1.3	79	17	69	28	7	50	31	53	49	76	1.12	−1.0	4	11.8	ne.	35	nw.	6	14	12	5	3.7	.0	.0
Titusville	43	5	36	30.07	30.12	----	58.8	−2.9	80	23	69	26	7	48	31	53	52	----	1.06	−1.6	8	----	nw.	----	----	----	12	13	6	----	.0	.0
East Gulf States							49.1	−0.9										75	2.57	−2.3										6.0		
Atlanta [1]	976	5	53	29.13	30.18	+.02	43.1	−1.6	69	16	52	10	7	34	27	38	33	74	1.49	−3.2	6	7.9	nw.	31	nw.	6	9	4	18	6.6	.7	.0
Macon	370	79	87	29.79	30.19	+.03	47.2	−.3	71	25	57	15	7	37	30	41	35	69	2.77	−1.2	5	6.2	nw.	21	nw.	6	11	9	11	5.0	.8	.0
Thomasville	273	40	58	29.88	30.19	+.04	51.7	−.8	76	28	62	17	7	41	32	46	43	----	1.60	−2.7	6	----	ne.	----	----	----	----	----	----	----	.0	.0
Apalachicola	35	11	----	30.13	30.17	----	51.6	−4.1	71	23	59	23	7	44	26	47	44	80	1.71	−3.4	7	7.8	n.	27	n.	9	14	8	9	4.4	.0	.0
Pensacola	56	149	185	30.11	30.17	+.02	52.0	−2.0	69	28	59	21	7	45	26	48	44	79	2.51	−2.1	6	11.5	e.	40	s.	17	12	13	6	4.8	.0	.0
Anniston	741	9	----	----	----	----	44.3	+.1	72	17	54	10	7	35	30	----	----	----	2.07	−3.0	11	----	nw.	----	----	----	12	5	14	----	T	.0
Birmingham	700	11	48	29.42	30.20	+.04	45.6	−.8	72	15	54	12	7	37	28	40	35	71	2.04	−3.1	12	7.0	s.	27	se.	17	10	4	17	6.2	1.5	.0
Mobile	57	86	161	30.12	30.18	+.03	51.8	−.4	72	15	60	22	7	44	26	47	43	77	3.28	−1.7	6	8.8	n.	32	s.	23	8	5	18	6.3	.0	.0
Montgomery	218	92	105	29.94	30.20	+.04	49.2	−.2	73	17	58	16	7	41	25	43	37	68	2.29	−2.6	7	6.6	n.	21	s.	17	9	6	16	6.3	T	.0
Meridian	375	67	92	29.77	30.18	+.02	47.8	+.1	72	14	56	15	7	40	30	43	39	77	2.98	−2.2	13	5.4	n.	20	sw.	17	8	6	17	6.7	.0	.0
Vicksburg	247	82	102	29.90	30.17	+.02	50.0	.0	73	13	57	19	9	43	24	45	40	73	4.16	−1.2	13	8.2	se.	32	e.	22	4	9	18	7.5	.0	.0
New Orleans	53	76	84	30.11	30.17	+.04	54.4	−1.2	74	31	62	30	7	47	22	49	45	78	3.97	−.8	7	6.9	se.	19	sw.	17	8	10	13	6.0	.0	.0
Port Eads, La	9	4	35	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
West Gulf States							50.1	−0.3										81	5.45	+2.4										7.5		
Shreveport	249	92	227	29.88	30.16	+.03	50.6	+1.5	72	14	57	20	9	44	27	47	42	78	7.63	+3.3	14	10.1	se.	37	ne.	22	6	5	20	7.4	.0	.0
Bentonville	1,303	12	38	28.80	30.21	+.08	37.0	−.5	61	29	45	8	9	29	30	----	----	----	3.21	+.8	11	6.5	s.	16	sw.	21	9	3	19	----	.2	.0
Fort Smith	457	79	94	29.69	30.19	+.06	41.7	−.4	64	30	48	14	6	35	25	38	33	76	3.15	+.4	13	7.4	e.	19	nw.	5	3	10	18	7.3	T	.0
Little Rock	357	94	102	29.79	30.18	+.04	43.0	−1.2	66	14	50	16	9	36	28	40	36	76	3.57	−.6	14	7.4	e.	21	nw.	5	6	5	20	7.5	.1	.0
Austin	605	68	90	29.47	30.11	----	51.5	+.5	72	25	58	25	9	45	29	48	46	84	5.21	+2.6	13	7.5	n.	24	n.	4	6	2	23	7.7	.0	.0
Brownsville	57	88	96	30.00	30.06	----	61.6	+.4	79	25	68	37	6	55	26	58	56	86	6.00	+4.4	16	10.2	se.	30	nw.	5	6	11	14	6.5	.0	.0
Corpus Christi	20	11	78	30.07	30.09	−.03	57.6	−.4	74	27	63	37	9	52	22	55	53	88	8.13	+6.7	10	10.6	se.	32	n.	5	5	3	23	7.7	.0	.0
Dallas	512	220	227	29.58	30.14	----	46.5	----	70	27	53	19	9	40	27	43	40	80	5.40	+3.0	13	10.4	n.	32	nw.	17	6	2	23	8.1	.0	.0
Fort Worth	679	92	110	29.42	30.15	+.03	46.1	−1.4	76	24	53	20	9	39	29	----	----	----	5.31	+3.4	15	8.6	n.	27	n.	17	6	3	22	7.7	.0	.0
Galveston	54	106	114	30.07	30.13	+.01	54.8	−1.6	68	25	59	32	9	50	18	52	50	85	4.41	+.7	13	11.3	e.	27	s.	22	6	4	21	7.3	.0	.0
Houston	138	292	314	29.98	30.13	----	54.8	+.4	75	25	62	27	9	48	25	----	----	----	7.14	+2.9	14	11.8	se.	29	nw.	5	7	1	23	7.6	.0	.0
Palestine	510	64	72	29.60	30.15	+.03	50.2	+.3	71	13	57	21	9	44	28	46	42	76	6.88	+3.2	16	7.0	s.	20	n.	5	4	5	22	7.9	.0	.0
Port Arthur	34	98	106	30.10	30.14	----	53.6	----	70	26	60	28	6	47	24	----	----	----	4.08	−1.2	14	13.1	se.	43	se.	16	5	7	19	7.5	.0	.0
San Antonio	693	242	301	29.38	30.11	.00	52.8	−.9	75	27	59	29	9	46	28	49	46	81	6.22	+4.6	16	10.6	e.	32	n.	5	4	5	22	7.7	.0	.0

[1] Observations taken at airport.

TABLE 2.—*Climatological data for Weather Bureau stations, December 1937*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01 inch or more	Wind: Average hourly velocity	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F		°F	°F.		°F	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
Ohio Valley and Tennessee							**34.7**	**−1.8**										**79**	**3.30**	**−0.2**										**7.4**		
Chattanooga	762	71	214	29.36	30.20	+0.04	42.6	−.7	67	17	50	12	7	35	25	38	33	71	3.18	−2.0	11	7.0	ne.	24	nw.	6	7	8	16	6.5	1.1	0.0
Knoxville	995	66	84	29.11	30.20	+.04	39.6	−.7	65	17	47	9	7	32	23	36	33	80	3.29	−1.2	13	5.3	w.	15	sw.	24	8	6	17	6.8	1.3	.0
Memphis	399	78	86	29.74	30.18	+.03	42.5	−1.1	68	14	49	13	9	36	24	40	35	75	3.92	−.6	13	7.4	e.	20	n.	5	5	7	19	7.3	1.2	.0
Nashville	546	168	188	29.61	30.21	+.06	39.4	−1.6	65	15	46	11	7	32	28	37	34	80	3.12	−1.1	13	7.9	sw.	24	nw.	31	5	4	22	7.7	.2	.0
Lexington	989	6																														
Louisville	525	188	234	29.60	30.20	+.06	34.4	−3.2	59	16	41	9	6	28	26	32	28	78	3.58	−.2	14	9.6	sw.	27	sw.	8	5	5	21	7.7	.4	.0
Evansville	431	76	116	29.70	30.19	+.06	34.6	−2.5	56	31	40	8	6	29	22	32	28	77	2.71	−.8	13	9.0	sw.	29	sw.	21	4	4	23	7.9	.9	.0
Indianapolis	822	194	230	29.25	30.17	+.05	29.5	−2.7	54	31	35	8	9	24	18	27	24	79	3.77	+.8	16	10.3	w.	29	w.	8	5	5	21	7.8	5.7	.0
Terre Haute	575	63	149	29.52	30.16	......	31.0	......	57	31	37	9	6	25	20	28	25	81	3.26	+.3	14	9.4	sw.	24	w.	8	7	4	20	7.3	.9	.0
Cincinnati	627	11	51	29.48	30.18	+.05	32.0	−1.4	55	16	38	9	9	26	26	30	26	80	3.65	+.7	16	8.0	sw.	26	sw.	8	6	6	19	7.4	4.6	.0
Columbus	822	90	210	29.26	30.16	+.04	31.0	−1.4	52	31	36	7	12	26	20	28	25	78	3.00	+.3	15	9.4	s.	38	sw.	8	7	5	19	7.2	1.9	.0
Dayton	899	60	163	29.17	30.16	......	30.4	−2.2	52	31	36	8	12	25	17	......	......	......	3.49	+.7	18	9.1	sw.	32	sw.	8	6	5	20	7.2	6.7	.0
Elkins	1,947	65	83	28.06	30.20	+.08	32.4	−.3	60	17	40	−5	12	25	30	29	26	80	3.07	−.4	19	6.5	w.	22	w.	8	5	8	18	7.2	9.5	.0
Parkersburg	637	77	84	29.47	30.18	+.04	33.6	−1.6	58	17	41	2	12	27	26	30	28	82	3.14	+.1	14	6.1	sw.	20	nw.	8	6	4	21	7.6	6.5	.0
Pittsburgh [1]	1,273	30	54	28.74	30.15	+.04	29.6	−4.6	54	18	36	6	9	23	24	27	24	82	2.90	+.1	14	10.3	sw.	33	sw.	22	6	6	19	7.4	4.2	.0
Lower Lake Region							**27.6**	**−1.8**										**80**	**2.35**	**−0.4**										**7.9**		
Buffalo	768	243	280	29.23	30.09	+.03	27.9	−1.9	42	4	32	9	13	23	19	26	22	80	3.78	+.4	19	17.0	w.	54	sw.	8	4	6	21	7.9	38.2	1.9
Canton	448	10	61	29.58	30.09	......	20.2	−2.5	41	4	28	−11	21	12	40	18	17	90	2.19	−.5	15	8.8	w.	29	w.	8	6	13	12	6.7	21.1	6.3
Ithaca	836	77	100	29.16	30.10	......	28.7	−.3	47	18	34	9	9	23	26	26	21	74	1.58	−.8	12	9.2	nw.	29	se.	31	3	6	22	7.8	8.0	.5
Oswego	335	71	85	29.71	30.09	+.03	28.0	−1.0	44	22	34	8	12	23	20	25	21	74	2.86	−.6	18	10.4	s.	30	w.	7	1	6	24	8.5	20.3	.7
Rochester	523	86	102	29.52	30.11	+.05	28.2	−1.1	44	22	33	12	13	24	20	25	20	72	2.15	−.6	15	9.3	sw.	33	w.	7	5	2	24	8.3	8.1	1.5
Syracuse	596	65	79	29.44	30.10	+.03	28.9	−.1	47	22	34	9	13	24	21	......	......	......	2.74	−.3	16	7.4	s.	23	sw.	7	4	7	20	7.7	10.0	1.8
Erie	714	130	166	29.32	30.12	+.05	29.1	−2.8	47	31	34	10	14	24	23	26	23	78	3.55	+.7	14	13.0	sw.	34	sw.	8	4	2	25	8.4	11.6	.0
Cleveland	762	267	318	29.27	30.12	+.03	30.1	−1.1	54	31	36	10	9	25	23	27	24	79	2.52	+.1	16	14.8	sw.	37	sw.	8	4	5	22	7.8	4.1	.0
Sandusky	629	5	67	29.44	30.15	+.06	28.8	−2.4	51	31	34	9	11	23	21	......	......	......	1.81	−.5	16	9.2	sw.	27	sw.	8	5	6	20	7.6	2.5	.0
Toledo	628	79	87	29.44	30.15	+.07	27.8	−2.6	50	31	32	7	9	23	18	26	23	81	1.52	−.8	12	9.7	w.	28	w.	8	6	5	20	7.3	1.2	.0
Fort Wayne	857	69	84	29.19	30.15	......	26.8	−2.9	51	31	32	4	9	21	20	25	23	86	1.77	−.8	16	9.3	w.	27	w.	8	4	3	24	8.2	1.8	.0
Detroit [1]	626	5	78	29.41	30.12	+.05	26.4	−2.9	43	31	32	7	14	21	21	24	21	81	1.70	−.6	12	10.1	sw.	32	sw.	8	4	2	25	8.3	6.1	.2
Upper Lake Region							**22.4**	**−2.0**										**82**	**1.47**	**−0.6**										**8.0**		
Alpena	609	13	89	29.38	30.07	+.05	23.2	−1.6	39	22	29	6	27	18	27	22	18	78	.90	−1.2	12	11.2	nw.	38	e.	31	2	6	23	8.1	8.8	4.1
Escanaba	612	41	49	29.38	30.08	+.05	20.2	−2.2	36	3	27	−3	27	13	38	19	14	75	.91	−.8	9	8.3	nw.	23	e.	31	3	7	21	7.8	13.0	7.5
Grand Rapids	707	70	244	29.31	30.11	+.06	26.6	−1.9	43	31	32	6	14	22	20	25	22	83	2.00	−.6	15	10.6	w.	31	sw.	21	1	4	26	8.9	14.9	.9
Lansing	878	5	90	29.13	30.10	......	24.6	−2.6	43	31	30	1	14	19	22	24	22	90	1.54	−.5	12	8.5	sw.	21	sw.	8	3	3	25	8.4	8.0	1.6
Ludington	637	5	54	29.36	30.08	......	25.4	−3.0	40	3	30	0	14	20	26	24	22	......	1.68	−.8	16	......	w.	......	......	......	3	4	24	......	18.5	2.5
Marquette	734	44	69	29.22	30.06	+.04	21.0	−1.6	37	27	27	5	26	15	31	19	17	87	2.31	−.4	19	8.0	nw.	30	sw.	2	1	5	25	8.7	27.0	14.0
Sault Ste. Marie	614	11	52	29.35	30.08	+.08	19.0	−1.5	37	3	25	−4	13	13	25	18	17	90	2.41	+.1	25	8.5	se.	27	nw.	28	3	3	25	8.6	38.0	14.6
Chicago	673	7	131	29.38	30.14	+.06	26.6	−2.2	52	31	32	6	9	22	20	25	21	79	1.27	−.8	12	10.6	w.	25	sw.	8	4	8	19	7.6	3.4	.0
Green Bay	617	109	141	29.39	30.10	+.06	20.7	−1.6	38	27	27	−3	23	14	34	20	16	80	.85	−.9	7	10.2	sw.	26	w.	8	6	1	24	7.9	6.4	2.0
Milwaukee	681	97	221	29.34	30.10	+.04	25.0	−1.1	44	31	30	4	9	20	28	23	19	78	1.42	−.3	7	12.7	w.	27	w.	8	3	8	20	7.8	4.5	.8
Duluth	1,133	5	47	28.79	30.08	+.03	13.7	−2.2	39	2	21	−10	20	6	30	12	8	80	.89	−.3	9	12.4	nw.	43	nw.	8	11	4	16	6.5	9.2	5.6
North Dakota							**11.7**	**−0.7**										**85**	**0.63**	**0.0**										**6.4**		
Moorhead, Minn.	940	50	58	29.07	30.14	+.06	10.7	−.8	39	2	20	−22	25	1	50	10	8	88	.94	+.2	7	9.6	nw.	26	nw.	31	6	5	20	7.3	16.6	8.2
Bismarck	1,674	8	57	28.25	30.14	+.06	13.6	−1.1	43	2	24	−18	24	3	50	12	9	82	.51	−.1	8	9.3	nw.	36	w.	31	5	11	15	6.3	5.9	1.8
Devils Lake	1,478	11	44	28.46	30.13	+.07	7.7	−1.8	36	21	17	−20	24	−2	41	7	5	90	.48	−.1	8	10.0	nw.	30	nw.	21	9	4	18	6.7	4.4	4.0
Williston	1,878	42	50	28.03	30.11	+.05	14.8	+1.0	40	30	24	−21	10	5	43	13	10	80	.60	.0	11	8.0	nw.	34	nw.	30	10	13	8	5.3	4.9	1.6
Upper Mississippi Valley							**25.2**	**−1.9**										**80**	**1.64**	**−0.1**										**7.5**		
Mpls.-St. P., Minn.	919	105	208	29.07	30.10	+.02	17.9	−1.7	43	2	25	−4	20	11	31	16	13	79	.53	−.4	11	11.3	nw.	30	nw.	22	6	7	18	6.9	5.4	.5
La Crosse	714	11	48	29.33	30.14	+.06	20.7	−1.6	41	31	27	0	11	14	30	19	16	81	.64	−.7	11	6.0	w.	17	nw.	4	3	6	22	7.9	4.7	1.6
Madison	974	70	78	29.02	30.12	+.04	20.8	−2.0	41	31	26	2	23	15	28	20	18	85	.93	−.7	10	8.6	w.	21	w.	9	4	7	20	7.5	3.6	1.2
Charles City	1,015	10	51	29.01	30.15	+.05	18.6	−1.8	40	31	27	−5	23	10	36	18	15	83	1.10	−.2	12	7.3	w.	25	w.	31	5	8	18	7.2	12.2	3.1
Davenport	606	66	161	29.47	30.16	+.06	25.4	−1.7	50	31	31	3	9	20	25	24	21	82	1.34	−.1	11	10.1	w.	30	nw.	31	5	7	19	7.4	7.3	T
Des Moines	861	5	99	29.21	30.16	+.05	24.5	−1.5	50	31	32	1	8	17	30	23	18	74	.68	−.5	8	10.0	nw.	33	w.	31	5	10	16	6.9	4.1	.0
Dubuque	699	60	79	29.35	30.14	+.04	22.8	−1.9	45	31	29	−1	23	16	29	21	18	80	1.18	−.3	12	6.3	nw.	18	nw.	22	5	3	23	7.8	9.1	.9
Keokuk	614	64	78	29.48	30.17	+.05	28.0	−1.6	56	31	34	2	8	22	23	26	21	75	1.90	+.4	13	8.4	sw.	22	nw.	31	4	6	21	7.6	.9	.0
Cairo	358	87	93	29.79	30.19	+.04	35.9	−1.9	62	16	42	9	9	30	23	34	30	81	3.04	−.4	12	8.7	sw.	23	n.	4	3	3	25	8.3	.5	.0
Peoria	609	11	45	29.47	30.17	+.06	26.8	−1.3	53	31	32	4	8	21	20	26	23	87	2.06	+.3	13	7.9	w.	23	w.	31	4	9	18	7.4	.8	.0
Springfield, Ill.	636	5	191	29.46	30.16	+.04	29.2	−2.5	58	31	35	7	6	24	20	27	24	81	2.31	+.1	9	11.4	w.	29	w.	8	5	6	20	7.8	T	.0
St. Louis	568	179	303	29.54	30.17	+.04	32.0	−2.9	59	31	38	6	6	26	24	30	25	77	3.91	+1.7	11	11.5	w.	28	w.	21	5	6	20	7.5	.4	.0
Missouri Valley							**27.7**	**−0.5**										**76**	**0.87**	**−0.3**										**6.1**		
Columbia, Mo.	784	6	66	29.30	30.16	+.04	31.5	−1.7	58	31	38	5	6	25	25	......	......	......	1.78	−.1	9	8.3	w.	23	nw.	4	6	6	19	7.1	.5	.0
Kansas City [1]	750	32	45	29.34	30.17	+.05	31.2	−1.3	59	30	38	4	8	24	23	29	24	77	.95	−.4	7	9.7	sw.	30	nw.	7	9	1	21	6.9	.5	.0
St. Joseph	967	11	49	29.10	30.17	......	29.0	......	55	30	36	2	8	22	24	27	23	79	.75	−.5	9	9.0	nw.	27	nw.	8	9	8	14	5.9	1.1	.0
Springfield, Mo.	1,324	98	104	28.71	30.16	+.03	33.6	−2.6	60	30	40	6	9	27	26	31	28	83	2.38	+.1	11	9.8	nw.	24	sw.	21	7	5	19	7.3	1.0	.0
Topeka	987	65	87	29.08	30.17	......	30.7	−1.3	57	30	38	3	8	24	26	28	25	79	.76	−.2	4	8.9	nw.	23	nw.	7	7	11	13	6.2	.5	.0
Lincoln	1,189	11	81	28.84	30.16	+.04	28.4	+.8	60	29	38	0	9	19	33	24	19	70	.17	−.6	7	9.9	s.	35	nw.	7	13	9	9	4.8	1.1	.0
Omaha [1]	982	31	44	29.07	30.17	+.06	26.9	+.5	59	29	36	−2	9	18	31	23	18	74	.15	−.8	6	11.1	nw.	39	nw.	31	10	7	14	5.9	.8	.0
Valentine	2,598	47	54	27.33	30.15	+.05	25.7	+1.1	56	28	37	−11	10	14	42	22	17	72	.30	−.3	6	9.5	w.	28	nw.	30	10	11	10	5.3	3.4	.0
Sioux City	1,138	64	106	28.88	30.15	+.03	24.2	+1.1	59	29	33	−5	9	15	35	21	16	74	.41	−.5	6	10.7	nw.	37	nw.	31	8	10	13	6.0	3.8	T
Huron	1,307	59	74	28.70	30.16	+.06	17.4	−1.3	51	2	28	−10	9	7	43	15	11	77	1.01	+.4	11	9.4	se.	38	nw.	31	11	8	12	5.4	17.1	3.0
Northern Slope							**25.0**	**+1.3**										**74**	**1.08**	**+0.3**										**7.2**		
Missoula	3,263	80	91	......	......	......	30.5	+6.0	46	28	36	7	8	25	20	......	......	......	2.47	+1.3	15	7.6	w.	32	e.	8	1	1	29	9.2	7.8	.5
Havre	2,507	11	67	27.36	30.12	+.07	19.6	−.8	49	1	30	−18	9	9	51	16	11	72	.14	−.5	6	9.8	sw.	35	w.	30	5	8	18	7.3	2.1	.0
Helena	4,124	85	111	25.81	30.12	−.01	28.2	+4.0	51	28	36	−10	23	21	35	24	17	64	1.50	+.7	12	9.1	sw.	32	s.	26	3	2	26	8.6	14.0	.6
Kalispell	2,973	48	56	29.66	30.11	+.04	27.2	+2.3	47	28	32	−4	9	22	23	26	23	83	1.23	−.2	19	4.9	w.	26	sw.	30	0	4	27	9.2	11.6	.6
Miles City	2,371	48	55	27.52	30.11	+.01	18.8	−2.2	45	30	30	−18	9	8	47	17	13	75	.42	−.2	5	6.6	s.	36	nw.	6	5	10	16	6.8	5.0	2.6
Rapid City	3,259	50	58	26.62	30.10	+.01	26.5	−.4	61	29	37	−11	9	16	37	22	18	75	.79	+.4	5	7.9	n.	30	w.	27	9	16	6	5.3	4.5	.0
Cheyenne [1]	6,144	5	39	23.90	30.11	+.02	26.6	−1.9	62	11	37	−9	8	16	42	23	19	74	1.68	+1.1	8	13.2	nw.	53	w.	27	7	7	17	6.6	16.2	.1
Lander	5,352	60	68	24.64	30.19	+.04	22.2	+1.8	65	11	34	−16	24	10	46	18	12	67	1.01	+.3	7	4.9	sw.	40	w.	30	6	8	17	6.8	10.4	1.6
Sheridan	3,790	10	47	26.10	30.15	......	22.8	......	55	30	34	−13	24	11	42	20	15	75	1.06	+.4	13	5.4	nw.	25	nw.	30	6	5	20	7.0	9.1	1.6
Yellowstone Park	6,241	12	46	23.87	30.21	+.05	22.5	+3.1	44	11	30	−11	8	14	28	20	16	72	1.34	+.6	19	9.2	s.	41	sw.	26	4	4	23	7.8	14.4	1.2
North Platte	2,821	11	51	27.12	30.16	+.06	28.0	+1.3	58	3	39	−2	8	17	37	23	20	78	.29	−.2	4	7.4	w.	22	n.	7	14	10	7	4.5	3.3	.0

[1] Observations taken at airport.

TABLE 2.—*Climatological data for Weather Bureau stations, December 1937*—Continued

District and station	Elevation of instruments			Pressure			Temperature of the air												Precipitation			Wind									
	Barometer above sea level	Thermometer above ground	Anemometer above ground	Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Total	Departure from normal	Days with 0.01 inch or more	Average hourly velocity	Prevailing direction	Maximum velocity: Miles per hour	Maximum velocity: Direction	Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F		°F	°F.		°F	°F.	°F.	°F.	%	In.	In.		Miles								0–10	In.	In.
Middle Slope							**33.1**	**−0.4**										**70**	**0.67**	**−0.2**										**5.4**		
Denver	5,292	106	113	24.71	30.11	+0.03	33.8	+1.5	68	11	45	−1	9	22	37	26	19	62	.84	+0.1	8	7.6	s.	28	w.	30	8	10	13	6.1	9.0	0.0
Pueblo	4,685	80	86	25.31	30.13	+.05	31.3	−.2	76	11	45	3	9	18	54	26	19	65	1.11	+.6	7	6.3	nw.	37	w.	27	15	10	6	4.1	11.8	.0
Concordia	1,392	50	58	28.64	30.17	+.06	30.2	−.5	57	28	39	−2	10	21	31	26	21	73	.14	−.5	4	8.3	n.	25	n.	24	13	11	7	4.9	1.6	.0
Dodge City	2,509	10	86	27.46	30.15	+.05	31.9	−.7	62	29	43	6	8	21	39	27	22	70	.25	−.3	5	10.3	n.	30	sw.	2	11	10	10	5.1	2.0	.0
Wichita	1,358	85	93	28.68	30.16	+.05	33.6	−1.0	55	30	41	8	9	26	27	30	25	73	.58	−.4	3	9.3	s.	26	sw.	30	9	13	9	5.2	T	.0
Oklahoma City	1,214	10	47	28.83	30.16	+.05	37.7	−1.6	58	31	44	16	6	31	24	35	31	79	1.12	−.4	8	9.3	n.	24	s.	3	5	9	17	7.0	T	.0
Southern Slope							**44.2**	**+0.1**										**74**	**1.82**	**+1.0**										**6.3**		
Abilene	1,738	10	52	28.28	30.13	+.02	45.4	−.6	72	12	53	21	9	38	33	41	37	78	2.89	+1.6	11	8.4	s.	24	s.	12	5	7	19	7.4	.0	.0
Amarillo	3,676	10	49	26.30	30.11	+.02	40.0	+3.0	71	12	52	18	10	28	46	32	24	62	.29	−.5	3	9.5	sw.	26	w.	12	11	7	13	5.8	2.3	.0
Del Rio	960	63	71	29.08	30.09	−.01	50.8	−1.4	70	27	57	32	10	45	28	48	45	86	3.93	+3.2	18	7.7	nw.	24	nw.	14	7	3	21	7.3	.0	.0
Roswell	3,566	75	85	26.43	30.11	+.04	40.5	−.7	80	12	54	15	6	28	43	35	28	68	.17	−.5	2	7.1	s.	34	ne.	17	12	11	8	4.6	.2	.0
Southern Plateau							**45.2**	**+4.2**										**61**	**0.73**	**−0.2**										**4.1**		
El Paso	3,778	82	101	26.24	30.08	+.05	47.4	+2.5	72	12	57	29	6	38	30	41	34	63	.91	+.4	8	7.5	nw.	25	e.	20	12	12	7	4.6	1.2	.0
Albuquerque [1]	4,972	5	39	25.10	30.10	------	37.8	+3.3	62	8	51	17	1	25	42	31	25	66	.48	.0	3	7.5	n.	31	se.	20	17	2	12	4.2	1.0	.0
Santa Fe	7,013	38	53	23.24	30.10	+.04	34.1	+3.4	53	12	44	13	21	24	29	28	20	60	.33	−.4	3	6.2	n.	26	n.	29	12	8	11	4.8	1.4	.0
Flagstaff	6,907	10	59	23.35	30.02	−.04	34.7	+6.3	60	11	45	13	22	24	39	30	----	76	1.91	−.2	9	8.3	nw.	33	ne.	20	5	15	11	----	2.0	T
Phoenix	1,107	39	51	28.85	30.02	−.02	56.9	+4.9	77	30	70	36	19	44	33	47	38	55	.41	−.6	2	5.1	e.	18	ne.	20	15	7	9	4.2	.0	.0
Yuma	141	9	54	29.88	30.03	−.02	60.3	+5.1	78	11	71	34	22	49	34	50	39	50	.35	−.2	5	6.8	n.	27	n.	20	21	5	5	2.7	.0	.0
Independence	3,957	5	26	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Middle Plateau							**34.4**	**+4.7**										**73**	**1.28**	**+0.4**										**5.8**		
Reno	4,527	61	76	25.53	30.14	−.01	36.8	+3.5	65	10	48	13	24	26	37	33	28	71	1.70	+.7	5	4.8	w.	35	sw.	24	12	8	11	4.9	.9	T
Tonopah	6,090	12	20	----	----	----	36.3		53	7	43	18	24	29	23	31	24	65	.05	----	2	----	se.	----	----	----	----	----	----	----	----	----
Winnemucca	4,344	18	56	25.70	30.18	.00	33.4	+3.4	62	10	46	8	26	21	40	30	27	81	1.11	.0	7	7.2	sw	30	sw.	10	9	7	15	6.0	10.6	1.0
Modena	5,473	10	43	24.66	30.10	−.02	34.0	+5.9	59	7	44	12	1	24	38	30	24	72	.69	−.1	7	8.9	sw.	38	sw.	23	8	3	20	6.7	2.0	.0
Salt Lake City [1]	4,227	32	46	25.80	30.14	−.01	36.3	----	57	11	46	12	24	27	27	32	28	75	1.27	----	6	8.0	se.	32	nw.	18	11	8	12	5.7	1.0	.0
Grand Junction	4,602	60	68	25.46	30.12	+.02	33.4	+5.9	54	12	42	12	25	25	28	30	26	75	1.63	+1.0	7	4.8	se.	21	sw.	23	9	10	12	5.9	5.9	.0
Northern Plateau							**35.6**	**+4.9**										**78**	**1.89**	**+0.2**										**8.0**		
Baker	3,471	36	54	26.50	30.16	.00	34.7	+7.4	51	11	41	13	23	28	28	32	28	77	1.34	−.4	11	6.2	s.	23	sw.	24	2	8	21	8.3	2.4	.0
Boise	2,739	79	87	27.27	30.19	−.01	37.5	+5.4	59	10	44	22	23	31	20	34	30	75	2.10	+.5	11	5.7	se.	23	se.	10	5	10	16	7.1	.1	.0
Pocatello	4,477	60	68	25.53	30.16	−.03	33.0	+5.3	52	11	40	12	8	26	24	30	26	74	1.42	+.2	9	8.2	se.	33	s.	11	6	7	18	7.1	.0	.0
Spokane	1,929	101	110	28.00	30.11	+.03	34.2	+3.7	50	28	38	17	9	30	16	32	29	82	2.76	+.6	13	7.1	s.	25	s.	26	1	4	26	8.8	13.5	.0
Walla Walla	991	57	65	29.02	30.12	.00	38.7	+3.2	61	28	43	24	23	34	20	36	32	78	2.07	.0	13	5.9	s.	24	w.	30	1	5	25	8.7	2.1	.0
Yakima	1,076	58	67	28.93	30.11	------	35.2	+4.5	57	28	40	23	23	30	23	33	30	82	1.64	+.3	11	4.8	se.	25	sw.	24	3	7	21	8.0	8.7	.0
North Pacific Coast Region							**45.4**	**+2.3**										**84**	**8.22**	**+1.0**										**5.0**		
North Head	211	11	56	29.81	30.04	+.01	46.0	+1.9	57	4	50	32	26	42	19	45	43	87	9.64	+.2	23	17.1	e.	70	s.	28	4	7	20	7.7	T	.0
Seattle	125	90	321	29.89	30.02	+.01	44.9	+3.2	56	10	49	30	23	41	18	43	40	82	8.49	+2.9	21	10.8	se.	43	sw.	28	1	8	22	8.4	1.0	.0
Tatoosh Island	86	10	54	29.87	29.97	+.01	45.8	+1.9	56	10	49	31	25	42	16	43	40	80	9.01	−4.4	25	19.2	e.	57	sw.	10	2	6	23	8.1	.2	.0
Medford [1]	1,329	29	58	28.69	30.14	------	40.5	------	61	29	46	25	1	34	25	39	37	87	3.49	+.4	9	----	nw.	----	----	----	0	4	27	9.1	2.0	.0
Portland, Oreg.	153	68	106	29.91	30.07	.00	44.0	+2.8	60	28	49	32	23	39	22	42	39	82	13.86	+7.1	20	7.3	s.	26	sw.	30	3	5	23	8.0	2.4	.0
Roseburg	510	45	76	29.55	30.11	.00	46.1	+4.3	64	28	50	31	25	42	22	44	41	83	4.83	−.5	15	4.2	s.	17	sw.	24	0	6	25	9.0	2.4	.0
Middle Pacific Coast Region							**51.9**	**+3.9**										**78**	**5.13**	**+0.4**										**6.0**		
Eureka	62	73	89	30.03	30.10	−.02	51.7	+3.5	70	20	58	35	23	45	27	48	45	80	4.26	−2.0	12	6.8	se.	32	s.	9	7	6	18	7.0	.0	.0
Redding [1]	722	20	34	------	------	------	52.0	+5.9	75	5	60	32	23	44	24	46	39	64	8.48	+2.9	8	7.9	nw.	36	s.	10	9	6	16	6.4	.5	.0
Sacramento	66	92	115	30.02	30.10	−.04	49.0	+2.8	68	10	57	33	27	41	27	47	44	83	4.06	+1.0	9	5.7	se.	27	sw.	11	10	11	10	5.2	.0	.0
San Francisco	155	112	132	29.90	30.07	−.05	54.8	+3.5	69	5	60	42	27	50	15	52	49	83	3.73	−.2	6	5.7	n.	31	sw.	11	12	5	14	5.3	.0	.0
South Pacific Region Region							**57.6**	**+4.7**										**67**	**2.53**	**+0.6**										**4.6**		
Fresno	327	97	105	29.75	30.12	−.01	50.8	+4.6	72	10	59	34	22	42	28	48	44	79	3.00	+1.6	6	4.8	nw.	20	se.	11	12	6	13	5.4	.0	.0
Los Angeles	338	159	191	29.68	30.05	−.02	61.9	+5.3	80	6	71	43	24	53	25	52	43	57	3.54	+.9	8	6.1	ne.	20	nw.	12	18	7	6	3.4	.0	.0
San Diego	87	62	70	29.94	30.03	−.04	60.2	+4.2	78	6	68	47	22	52	26	53	46	65	1.06	−.8	8	5.2	nw.	22	n.	20	13	6	12	5.1	.0	.0
West Indies																																
San Juan, P. R.	82	9	54	29.87	29.96	------	76.8	+.5	87	3	81	70	6	73	16	----	----	---	2.95	−2.6	19	13.4	e.	33	e.	25	0	21	10	6.6	.0	.0
Panama Canal																																
Balboa Heights	118	6	92	------	[3]29.80	−.01	78.7	−1.3	91	28	84	71	21	73	18	----	----	[2]86	16.81	+12.3	18	6.2	nw.	30	nw.	6	1	14	16	6.8	.0	.0
Cristobal	36	6	97	------	[3]29.82	−.02	79.6	−.3	87	28	84	73	14	76	11	75	74	[2]87	32.94	+21.7	25	11.2	n.	33	nw.	6	6	5	20	7.5	.0	.0
Alaska																																
Fairbanks	454	11	87	[3]29.56	[3]30.14	------	−7.2	−.2	35	18	3	−40	28	−17	50	−6	−11	78	.28	−.4	5	5.5	n.	23	s.	22	17	6	8	4.0	10.5	10.6
Juneau	80	96	116	[3]29.78	[3]29.88	------	26.0	−5.2	49	4	30	−1	10	22	20	24	16	68	7.03	−.7	18	9.4	ne.	31	ne.	3	8	1	22	7.2	20.4	7.5
Nome	22	5	32	------	[3]30.09	------	12.9	+6.4	39	7	20	−15	29	5	31	----	----	70	.33	−.8	6	9.9	ne.	43	n.	18	14	4	13	----	3.2	1.2
Hawaiian Islands																																
Honolulu	38	86	100	[3]29.92	[3]29.96	------	73.8	+1.4	82	2	79	65	24	69	13	68	65	77	5.45	+1.5	15	8.4	e.	35	ne.	23	11	14	6	4.8	.0	.0

[1] Observations taken at airport,
[2] Observations taken bihourly.
[3] Pressure not reduced to mean of 24 hours.

TABLE 3.—*Data furnished by the Canadian Meteorological Service, December 1937*

Stations	Altitude above mean sea level, Jan. 1, 1919	Pressure			Temperature of the air						Precipitation		
		Station reduced to mean of 24 hours	Sea level reduced to mean of 24 hours	Departure from normal	Mean max.+mean min.÷2	Departure from normal	Mean maximum	Mean minimum	Highest	Lowest	Total	Departure from normal	Total snowfall
	Feet	*In.*	*In.*	*In.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	*In.*	*In.*	*In.*
Cape Race, Newfoundland	99												
Sydney, Cape Breton Island	48	29.85	29.91	+0.01	30.9	+1.9	35.8	26.0	50	7	8.94	+3.59	23.1
Halifax, Nova Scotia	88	29.71	29.99	+.04	29.4	+1.1	34.1	24.7	50	4	6.91	+1.51	6.9
Yarmouth, Nova Scotia	65	29.90	30.01	+.05	31.6	+.6	36.7	26.5	52	11	5.80	+1.05	22.8
Charlottetown, Prince Edward Island	38	29.98	29.99	+.07	26.4	+1.2	31.2	21.5	47	−6	6.68	+2.07	33.6
Chatham, New Brunswick	28	29.89	30.01	+.06	17.6	−1.4	25.5	9.8	40	−20	1.66	−1.53	15.3
Father Point, Quebec	20	30.01	30.03	+.07	18.4	+1.9	24.1	12.6	40	−10	.36	−2.35	3.2
Quebec, Quebec	296	29.74	30.08	+.07	17.4	+1.8	22.4	12.4	38	−12	3.09	−.30	27.6
Doucet, Quebec	1,236	28.62	30.03	+.01	5.1	−2.9	15.8	−5.6	30	−48	3.02	+.28	30.2
Montreal, Quebec	187	29.88	30.10	+.07	19.1	−.5	24.0	14.2	36	−7	3.76	+.02	37.6
Ottawa, Ontario	236	29.82	30.08	+.03	14.9	−2.8	22.8	7.0	36	−23	2.64	−.20	26.2
Kingston, Ontario	285	29.76	30.08	+.03	24.3	−.1	30.4	18.2	41	−3	3.45	+.50	26.1
Toronto, Ontario	379	29.68	30.10	+.04	27.4	−.1	33.0	21.9	43	2	1.69	−.80	9.3
Cochrane, Ontario	930	28.94	30.01	−.05	7.6	−.4	15.2	.0	33	−32	3.55	+1.98	35.1
White River, Ontario	1,244	28.64	30.06	+.05	5.8	−2.8	17.4	−5.8	35	−30	4.38	+2.58	43.5
London, Ontario	808	29.19	30.10	+.02	22.8	−4.0	29.2	16.3	41	−9	2.82	−.72	19.9
Southampton, Ontario	656	29.34	30.06	+.04	23.9	−2.6	29.8	18.0	41	−6	3.61	−.27	35.3
Parry Sound, Ontario	688	29.34	30.08	+.06	20.8	.0	27.5	14.2	38	−8	5.47	+1.02	48.0
Port Arthur, Ontario	644	29.35	30.10	+.06	8.6	−5.0	18.3	−1.0	35	−18	4.65	+3.76	46.5
Winnipeg, Manitoba	760	29.24	30.14	+.04	5.6	−.4	14.5	−3.4	38	−25	1.37	+.46	13.7
Minnedosa, Manitoba	1,690	28.20	30.13	+.05	5.4	−2.6	14.6	−3.6	38	−32	.88	+.29	8.8
Le Pas, Manitoba	860	29.10	30.16	+.11	−3.4	−3.6	5.2	−11.9	37	−38	3.14	+2.60	31.4
Qu'Appelle, Saskatchewan	2,115	27.68	30.08	.00	7.1	−2.3	15.6	−1.4	38	−28	.75	+.02	7.5
Moose Jaw, Saskatchewan	1,759	28.00	30.07	−.04	11.4	+.3	20.6	1.9	40	−22	.30	−.29	3.0
Swift Current, Saskatchewan	2,392	27.40	30.10	+.02	12.2	−4.8	22.0	2.5	42	−25	.79	+.15	7.8
Medicine Hat, Alberta	2,365	27.48	30.08	+.02	17.8	−1.6	27.3	8.3	46	−21	.23	−.45	2.3
Calgary, Alberta	3,540	26.24	30.08	+.03	16.4	−4.1	26.1	6.6	56	−22	.30	−.27	3.0
Banff, Alberta	4,521												
Prince Albert, Saskatchewan	1,450	28.50	30.16	+.08	1.2	−4.0	11.5	−9.1	42	−37	.90	+.18	9.0
Battleford, Saskatchewan	1,592	28.28	30.14	+.06	−1.0	−7.2	11.0	−13.0	41	−42	.59	+.18	5.9
Edmonton, Alberta	2,150	27.66	30.10	+.12	5.7	−8.3	13.6	−2.2	48	−30	1.02	+.26	8.5
Kamloops, British Columbia	1,262	28.75	30.15	+.04	27.8	+.6	32.2	23.3	48	−2	1.15	+.09	8.8
Victoria, British Columbia	230	29.75	30.01	−.03	42.4	+1.4	46.3	38.6	52	27	7.87	+2.49	9.3
Barkerville, British Columbia	4,180												
Estevan Point, British Columbia	20	29.92	29.94	−.01	43.8	+1.7	48.3	39.3	55	21	14.46	−1.24	14.7
Prince Rupert, British Columbia	170	29.62	29.81	−.02				32.0		9	9.54	−2.18	7.2
St. George's, Bermuda	158		30.04	−.08	66.0	+1.2	70.5	61.6	78	55	7.34	+2.43	.0
LATE REPORTS FOR NOVEMBER 1937													
Cape Race, Newfoundland	99				36.6	−0.8	42.6	30.6	52	18	2.23	−3.36	1.0
Calgary, Alberta	3,540	26.28	30.10	+0.05	22.8	−3.6	31.3	14.2	59	−.7	1.28	+.54	12.8

TABLE 4.—*Severe local storms, December 1937*

[Compiled by Mary O. Souder from reports submitted by Weather Bureau Officials]

[The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A revised list of tornadoes will appear in the United States Meteorological Yearbook]

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks
Knoxville, Tenn., and vicinity	5-7			1		Rain, sleet, and snow.	Streets and sidewalks slippery; several persons injured. Near Mascot, Tenn., on the 6th, a person was killed due to the skidding of an automobile.
Michigan, southwestern lower portion.	5-10					Heavy snow	Traffic completely stopped on some roads because of drifting.
Springfield, Mo.	7	3:30 p. m.-midnight.				Snow and glaze	Driving extremely dangerous; several minor traffic accidents occurred.
New York State, central portion.	7					Heavy snow	Much drifting; many roads blocked; automobile and bus traffic greatly delayed.
Grand Rapids, Mich., and vicinity.	8					Snow squalls	Traffic hampered by snow and low visibility during heavy squalls and by slippery pavements and snowdrifts.
Buffalo to Niagara Falls, N. Y., and vicinities.	8-10			4	$2,000,000	Blizzard	Snow that continued from the 7th, ended 9:30 p. m., of the 10th with maximum wind velocities from 54 miles on the 8th to 40 miles on the 10th, made this storm, especially on the 10th, the most sensational and costly in the history of the Buffalo area. 8th: 13.5 inches of snow measured in the Hertel Ave. section, while 5.5 inches fell in downtown Buffalo. Drifts in north Buffalo several feet high with traffic brought almost to standstill. Bus service to Niagara Falls canceled as well as airplane traffic from the Buffalo Airport. Many persons unable to get to work, while others were hours late. Over 300 cars stalled near Getzville and about 250 men marooned at the Huntley electric plant on River Rd. 10th: 13.5 inches of snow recorded at Hertel Ave., twice as much as that recorded in the downtown section, fell on this date in the same districts during this second storm as that of the 8th, resulting in a measurement of 37.0 inches on the ground at Hertel Ave. at 3 p. m., of the 10th. Snowfall was 3 to 4 feet deep on the level in such suburbs as Kenmore and 5 to 8 feet more in great drifts. Bus and street-car traffic badly disorganized; service on some lines abandoned.
Nevada, western portion	9-12					Rain and flood	The valleys of the east slope of the Sierra flooded; considerable damage to highways, small bridges and haystacks; and loss to poultry on ranches lying along the streams.

TABLE 4.—*Severe local storms, December 1937*—Continued

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks
Montana, northern portion	10			3		Glaze	Several automobile accidents, because of slippery roads, resulted in 3 deaths.
Helena, Mont., and vicinity	10-11					do	Most severe and the heaviest accumulation of glaze in the history of this station, ice forming on pavements and all exposed objects. Storm began at 1:50 p. m., of the 10th and glaze began melting after 6:55 a. m., of the 11th.
Oklahoma City, Okla	10-11					do	All exposed surfaces coated with ice; traffic delayed.
Miles City, Mont	11-12					do	Streets and sidewalks so slippery that travel on foot or by car was all but impossible.
Concordia, Kans	12-14					do	Ice formed on pavements, sidewalks, trees, wires, etc. Driving very hazardous and walking unsafe.
Evansville, Ind., and vicinity	13					do	Many slight accidents due to slippery streets. Bus service to nearby towns discontinued on the 13th and resumed during the afternoon of the 14th.
Dodge City, Kans	13-14					do	Sleet on the 13th and glaze on the 13th and 14th. Numerous accidents reported because of icy pavements.
Wichita, Kans	13-14					do	Rain fell on sleet, freezing as it hit. Automobile traffic almost at standstill all day of the 14th.
Kansas City, Mo	13-15					Rain and sleet	Extremely slippery conditions due to freezing rain.
Oklahoma, northern half of State.	13-15				60,000	Glaze	The areas of heaviest glaze deposit were from Oklahoma City westward to slightly beyond El Reno, Blackwell, and immediate vicinity, and from Perry to the west of Enid and Waukomis. Weight of ice on wires ranged from 5 to 7 ounces per linear foot at Oklahoma City. Hundreds of utility poles down; thousands left leaning with miles of wire down $60,000 damage to Southwestern Bell Telephone Co.; heavy unestimated financial losses to other utility companies. Much damage to fruit, trees, and shrubbery.
Des Moines, Iowa, and vicinity	14-15					do	Sidewalks and roads slippery; driving hazardous. 5 persons injured and many crashes reported. Plane travel discontinued over most of the area and buses hours behind schedule.
Ohio	14-15					Rain and sleet	Streets and sidewalks ice-coated; traffic impeded; many accidents reported.
Milwaukee, Wis	14-15					do	Streets and walks slippery. Number of persons injured by falling or because of motor accidents.
Cleveland, Ohio	15	2:55 a. m.-6 p. m.				Glaze	Traffic interrupted and many accidents reported because of extremely slippery streets.
Chicago, Ill.[1]	15			2		do	Man killed in a motor accident; another because of falling; both due to slippery streets.
Detroit, Mich	15					Snow and sleet	Streets and highways slippery; several persons injured.
Grand Rapids, Mich	15					Glaze	Motor traffic considerably interrupted because of ice on pavements and by rain and sleet freezing to windshields.
Harrisburg, Pa	15-16					Glaze and snow	Streets and sidewalks slippery; bus schedules interrupted; plane flights canceled. 5 persons injured in automobile accidents and 16 pedestrians treated for injuries received in falls, 1 seriously injured.
New York City, N. Y., and vicinity.	16			1		Sleet	Thousands of persons were delayed in getting to work or school. Electric wires and streets ice-coated. Several persons injured, 2 seriously. All trains of the Lackawanna, in northern New Jersey, delayed.
Providence, R. I., and vicinity	17			1		Rain and glaze	Rain froze in all parts of the State causing hazardous driving. In Foster a man was killed when his car skidded off the road.
Lansing and central Michigan[1]	18			1		Glaze	Bare pavements with thin coatings of ice in many spots made driving hazardous; 12 persons injured.
Davenport, Iowa	23	8:45-9:40 p. m.				Sleet, snow and rain.	Traffic on highway dangerous; wire communication disrupted.
Marquette, Mich., vicinity of	24			2		Wind and snow	2 men, in a fishing boat, about a mile out from the breakwater, unable to make port, were drowned.
Michigan, southern portion	24					Glaze	Hazardous driving conditions prevailed throughout the entire southern portion below the Bay City line. Sanding operations carried on continuously, but freezing rain quickly undid this work. Several pedestrians injured.
Columbia Falls, Mont., and vicinity.	26					Blizzard	No trains from the east were able to come in while trains from the west were several hours late.
Yakima, Wash., and vicinity	26-27					Snow	Power lines down; over 200 telephones out of commission. Snowfall heavier in outlying districts and all communication lines westward were useless for 2 days.
Portland, Oreg., and vicinity	26-30					Heavy rains	Many slides resulted from this storm and water covered highways greatly hindering traffic and putting many phones out of order.
Springfield, Mo	27-30					Dense fog and mist	Visibility reduced to zero; driving extremely hazardous; traffic interrupted; several accidents due to foggy conditions. Considerable mist accompanied this storm.
Lake Superior, vicinity of	31	A. m.				Glaze, sleet, snow and wind.	Number of poles and wires down between Duluth and Virginia, Minn. Traffic delayed. Heavy snow occurred on the north shore of Lake Superior.
Buffalo, N. Y	31	P. m.				Snow and sleet	Streets and sidewalks covered with ice an inch or more in thickness from packed snow and sleet followed by frozen rain. Motor traffic interrupted; windshields covered with ice. One power line out of commission, otherwise only minor damage was reported.
Grand Marais, Minn., and vicinity.	31				60,000	Wind	Strong easterly winds created high waves on Lake Superior resulting in considerable damage along the entire north shore of the lake. Heaviest loss occurred at Grand Marais where a number of boat and fish houses were demolished by the force of the waves which swept over the dock and flooded the main street of the town. The storm described by local fishermen as the most severe "Northeaster" in the past 32 years.
Moorhead, Minn	31					Blizzard	Both old and new snow drifted; many side roads blocked.
Canton, N. Y	31					Wind and snow	Highways blocked by drifting snow. Many motorists obliged to abandon their cars and seek shelter in framehouses along the road. Strong wind and intense cold caused much temporary suffering and inconvenience.

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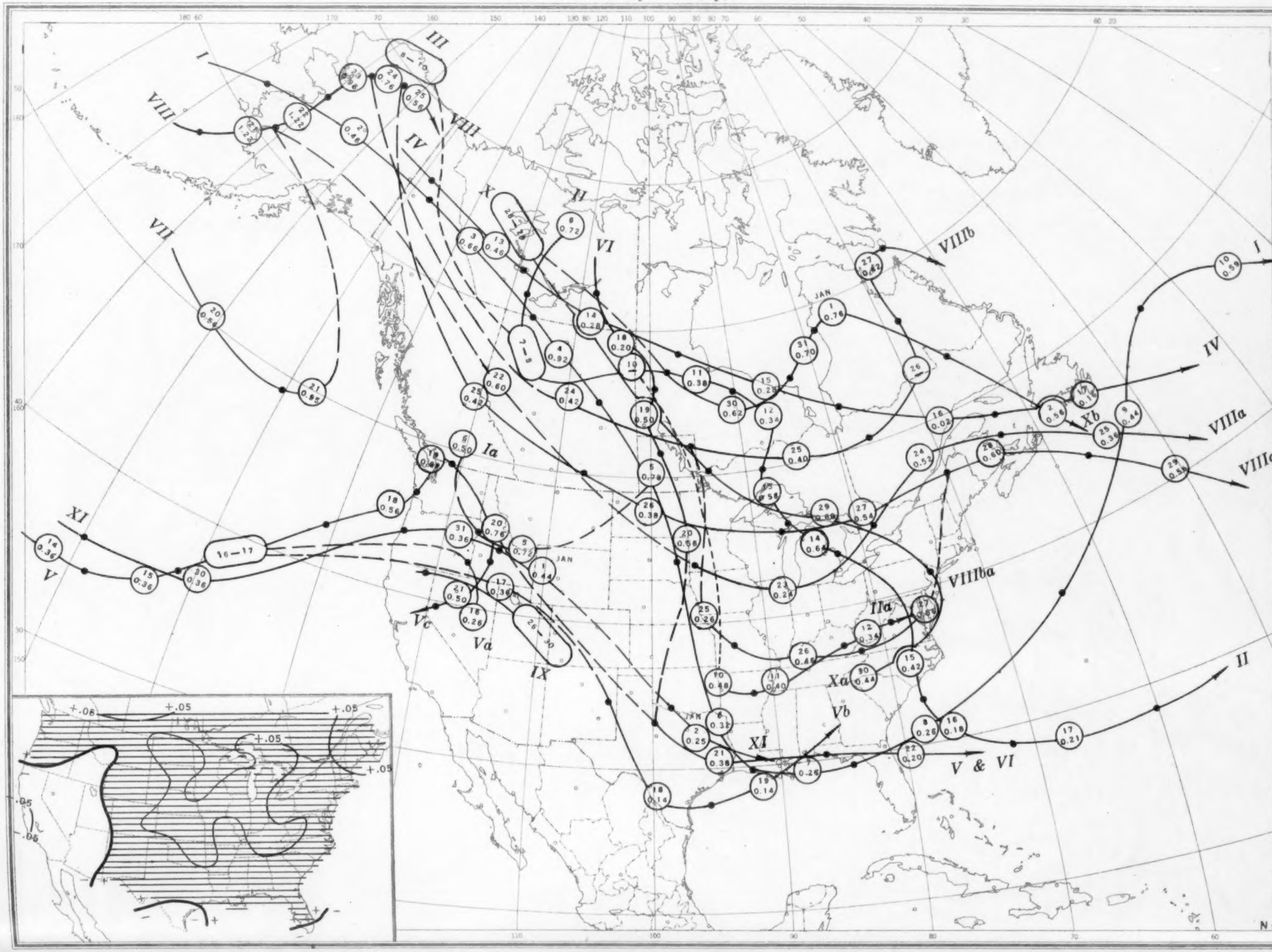
Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks
Arcade, N. Y., and vicinity	*Nov.* 28	4:15 p. m.	167	0		Tornado	Buildings wrecked or unroofed; windows broken; trees blown down or uprooted; monuments in the cemetery at Delevan toppled over. Storm hit lumber yard where piles of lumber were blown over. A 2-by-4, 6 feet long, blown through a rear window of a house and carried on through to the front of the upstairs rooms. Garage twisted and moved several feet; 6 trees, 60 feet high uprooted. No injuries reported.

[1] From press reports.

Chart I. Departure (°F.) of the Mean Temperature from the Normal, December 1937

Chart II. Tracks of Centers of Anticyclones, December 1937. (Inset) Departure of Monthly Mean Pressure from Normal

(Plotted by W. P. Day)

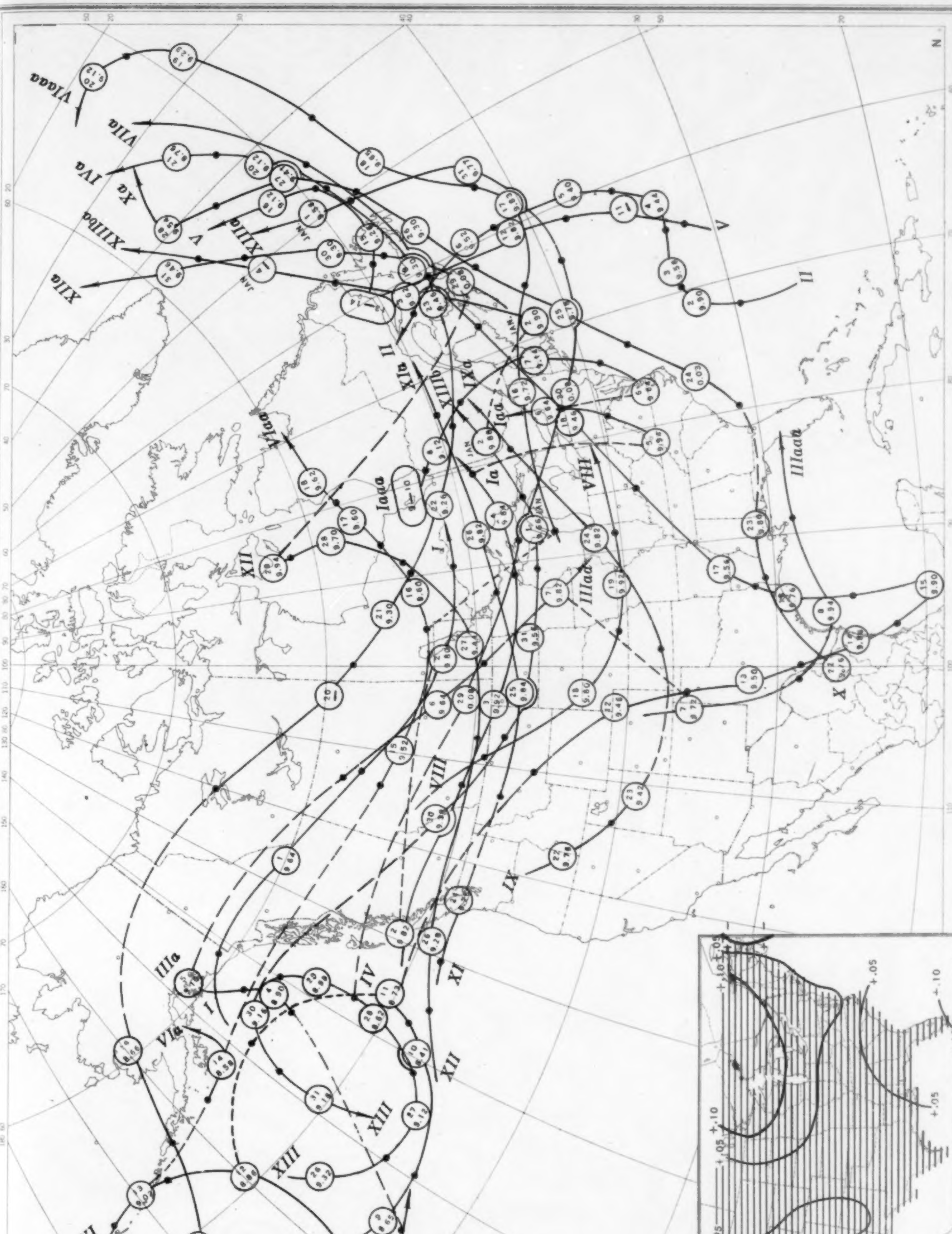


Circle indicates position of anticyclone at 7:30 a. m. (75th meridian time), with barometric reading. Dot indicates position of anticyclone at 7:30 p. m. (75th meridian time).

Chart III. Tracks of Centers of Cyclones, December 1937. (Inset) Change in Mean Pressure from Preceding Month

(Plotted by W. P. Day)

Chart III. Tracks of Centers of Cyclones, December 1937. (Inset) Change in Mean Pressure from Preceding Month
(Plotted by W. P. Day)



Circle indicates position of cyclone at 7:30 a. m. (75th meridian time), with barometric reading. Dot indicates position of cyclone at 7:30 p. m. (75th meridian time).

Chart IV. Percentage of Clear Sky Between Sunrise and Sunset, December 1937

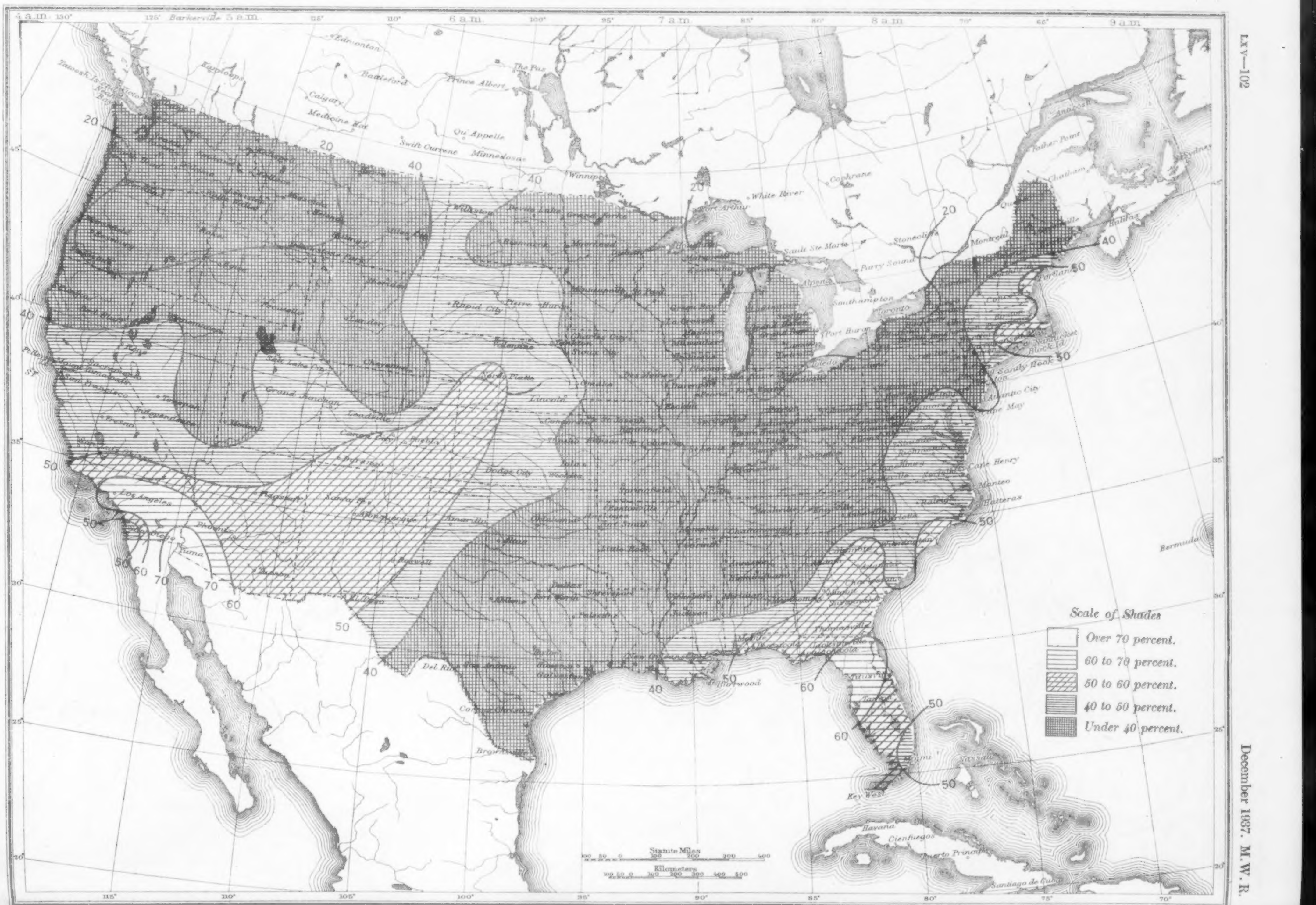


Chart V. Total Precipitation, Inches, December 1937. (Inset) Departure of Precipitation from Normal

Chart V. Total Precipitation, Inches, December 1937. (Inset) Departure of Precipitation from Normal

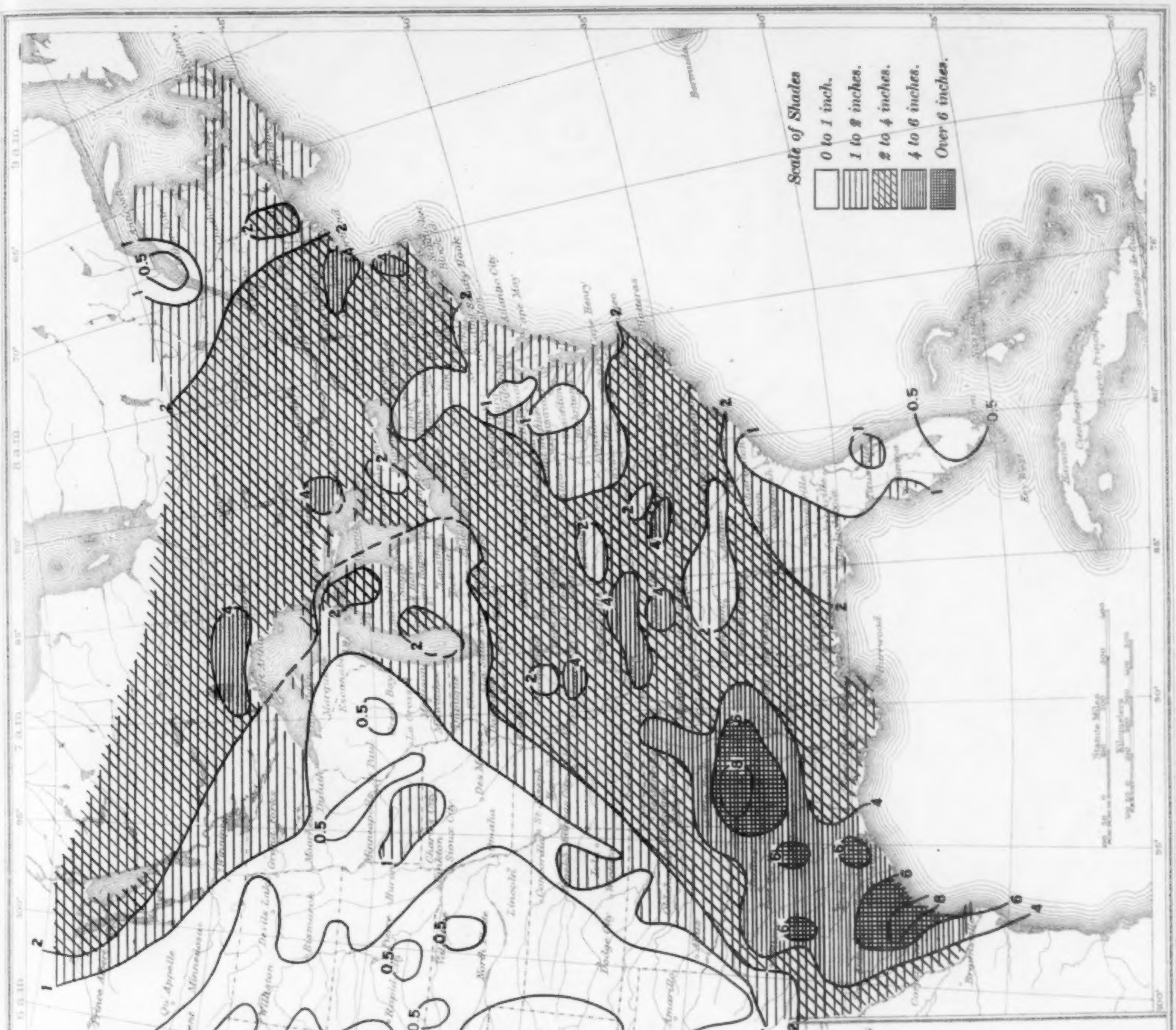


Chart VI. Isobars at Sea Level and Isotherms at Surface; Prevailing Winds, December 1937

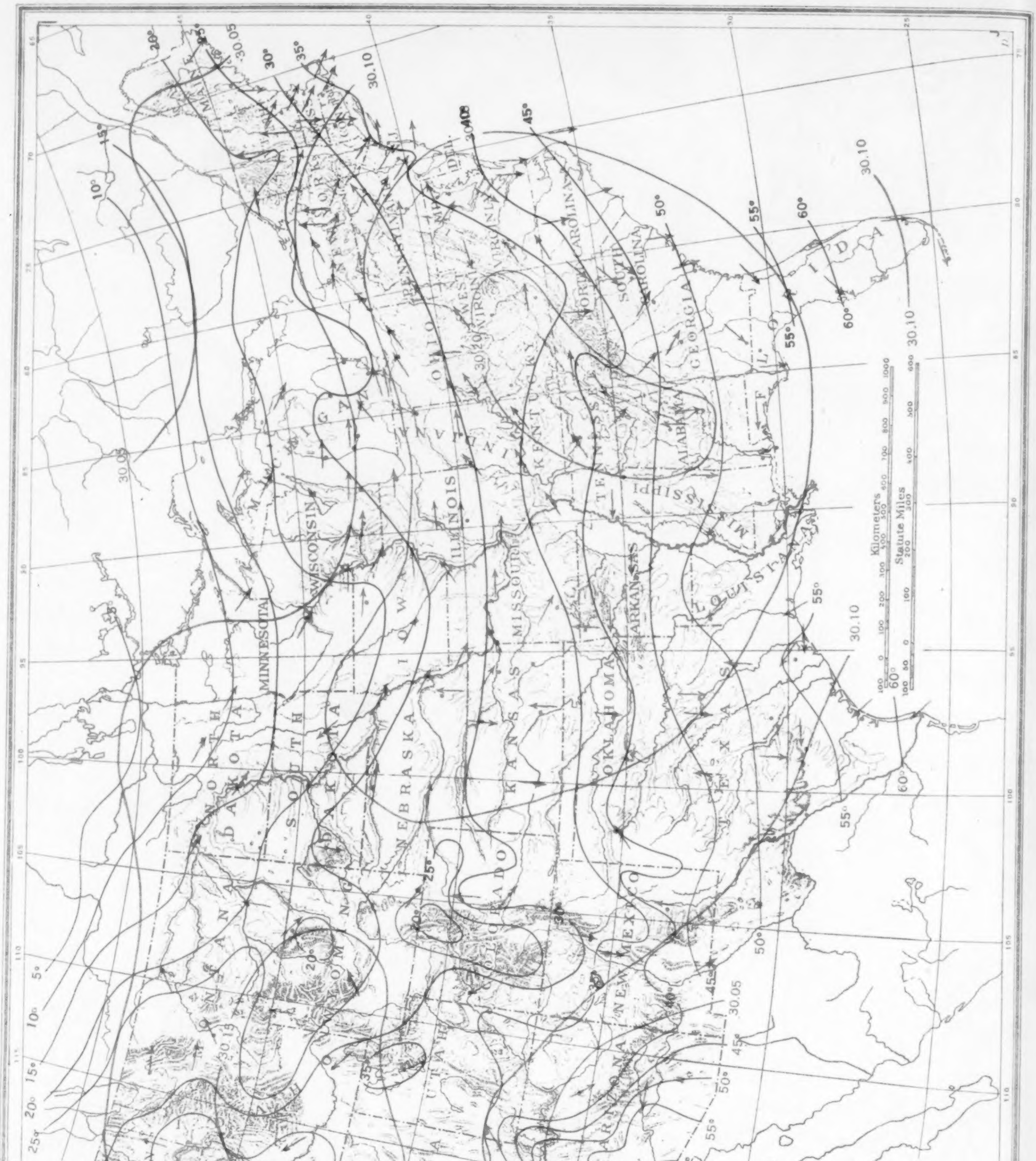


Chart VII. Wind Roses for Selected Stations, December 1937

Chart VII. Wind Roses for Selected Stations, December 1937
(Plotted by W. W. Reed)

Chart VIII. Total Snowfall, Inches, December 1937. (Inset) Depth of Snow on Ground at 7:30 p.m., Monday, Dec. 27 1937

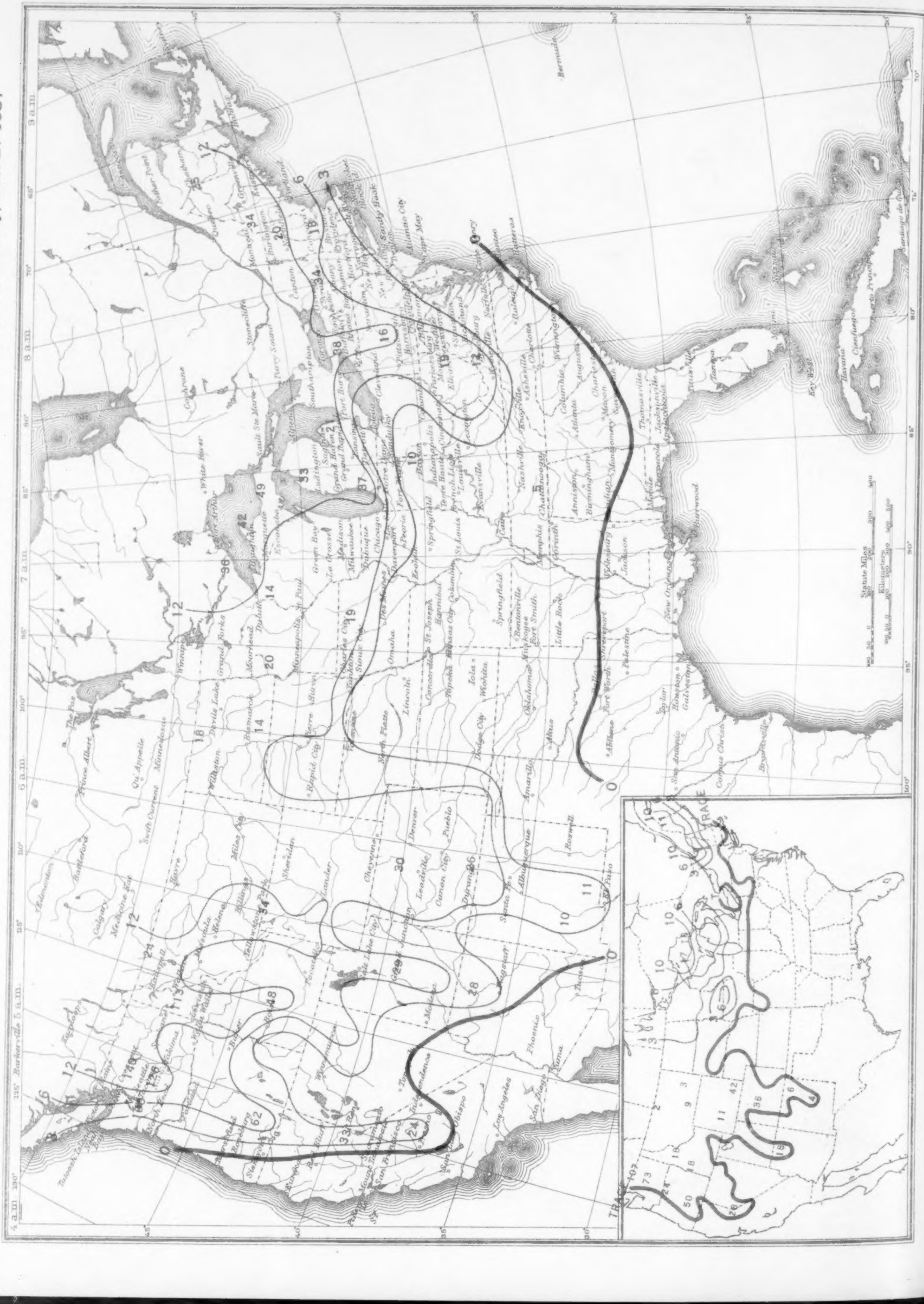


Chart IX. Weather Map of North Atlantic Ocean, December 4, 1937
(Plotted from the Weather Bureau Northern Hemisphere Chart)

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(Plotted from the Weather Bureau Northern Hemisphere Chart)

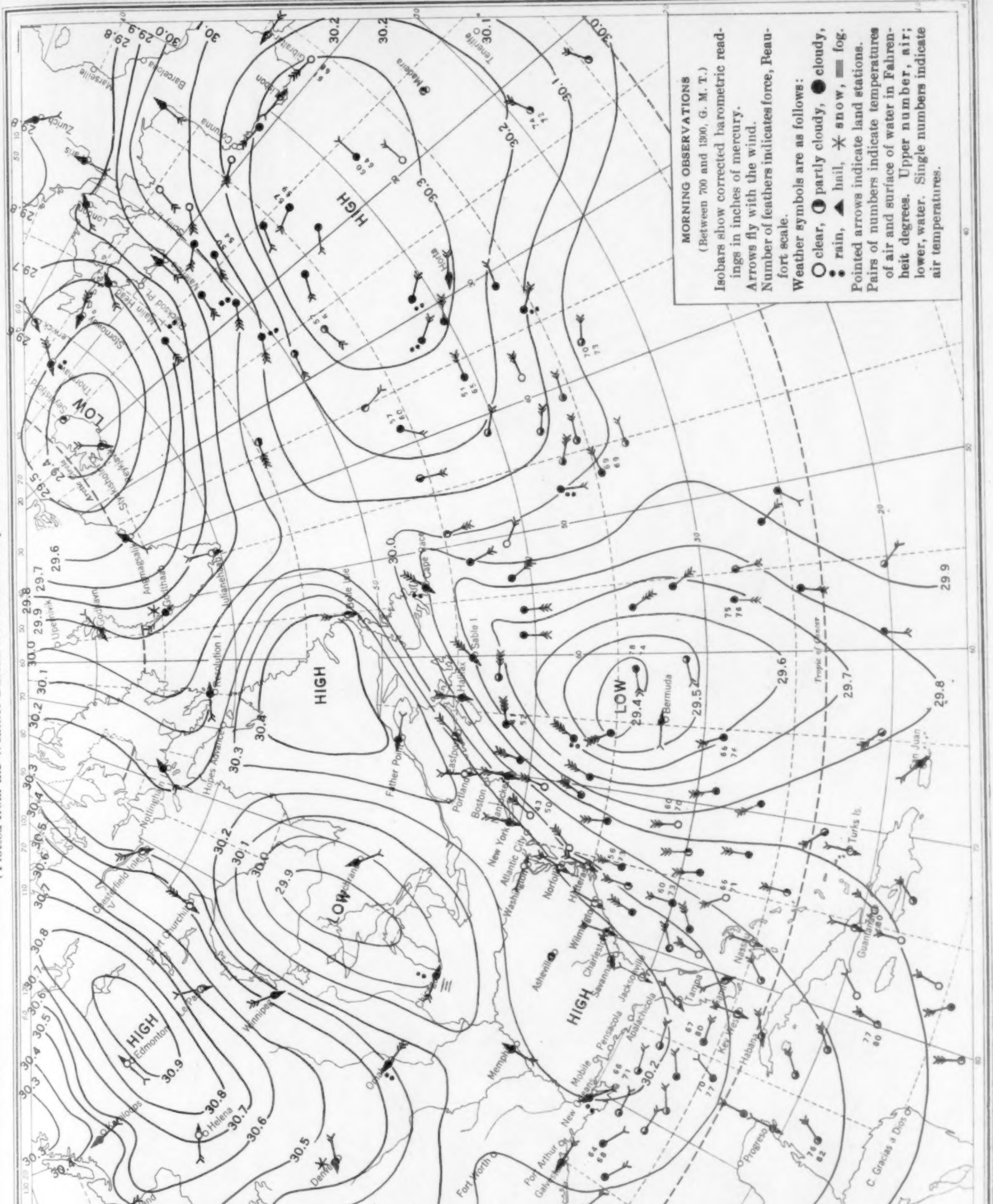
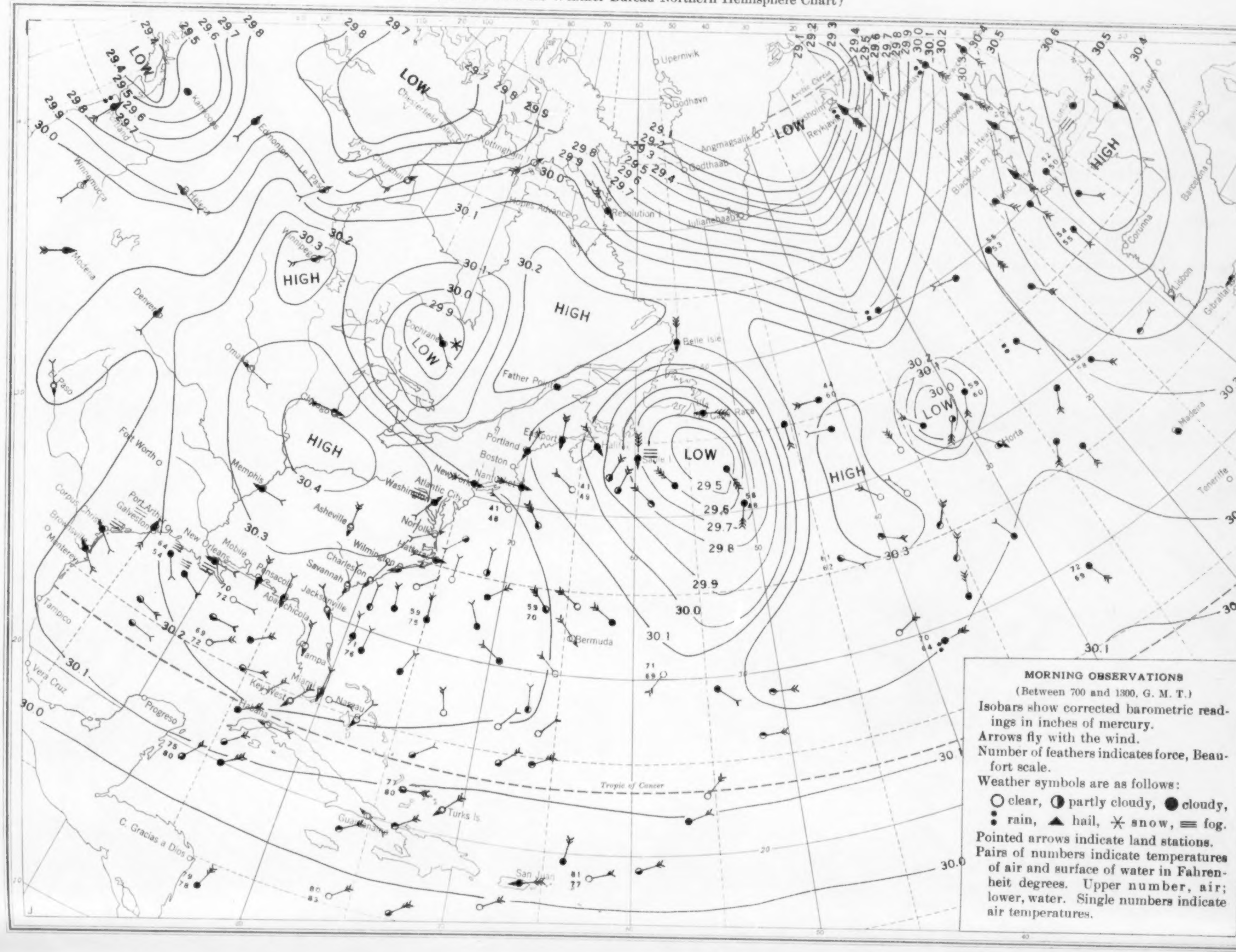


Chart X. Weather Map of North Atlantic Ocean, December 26, 1937

(Plotted from the Weather Bureau Northern Hemisphere Chart)



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